# Canadian Forest Service Research and the National Forest Science and Technology Course of Action


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# On Course
# Canadian Forest Service Research and the National Forest Science and Technology Course of Action

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For over 100 years, the Canadian Forest Service (CFS), Natural Resources Canada, has existed as Canada's national forest science research organization. The CFS is dedicated to promoting the sustainable development of Canada's forests and the competitiveness of Canada's forest sector for the benefit of present and future generations of Canadians. To this end, the CFS continuously produces and communicates innovative forest science and technology and provides expert guidance in matters of trade, economics, and forest policy development to its clients in government, industry, academia, and the forest community.

**The CFS generates and transfers forest science information.** The CFS science and technology (S&T) program investigates the health, composition, function, development and response to change of Canada's forests and forest ecosystems. The CFS transforms scientific data into decision-making tools, inventory technologies, biotechnology, and adaptive forest management practices. Its world-class research staff totals approximately 500 research scientists and technicians (90 of whom are adjunct professors in Canadian universities) and is supplemented by 72 research positions in partnerships, 40 graduate students, 30 research fellowships, 250 summer students, and 35 First Nations students. CFS research provides forest managers with the expertise and innovative techniques required to meet growing global demands for forest products while maintaining the productivity, biodiversity, and regeneration capacity of Canadian forests. At the CFS, forest research is specifically directed to fulfilling Canada's goal and international obligation of achieving fully sustainable forest management.

**The CFS encourages national consensus in forest science.** It utilizes its multidisciplinary science capability to develop partnerships and collaborative agreements with members of the broader scientific community, provincial and territorial resource management agencies, and forest stakeholders sharing common interests and objectives. The CFS conducts research that is long-term in nature and provides commitment and financing vital to meeting complex forest sector challenges. The CFS recognizes the critical importance of forestry to hundreds of Canadian communities and the increasing involvement of First Nations in forest management by conducting innovative socioeconomic research and assisting in the documentation of traditional Aboriginal forest knowledge. CFS researchers forge regional and community level partnerships by working with stakeholders in the Canadian Model Forest Program and the First Nation Forestry Program.

**The CFS gathers and disseminates forestry data that provides the world with a picture of Canada's forest land base on a continental scale.** It evaluates national forest health and tabulates national forest inventory data, providing information crucial to the fulfilment of Canada's commitments under international agreements such as the Montreal Process on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forest and the Kyoto Protocol to the United Nations Framework Convention on Climate Change. The CFS develops and utilizes advanced satellite and airborne remote-sensing technologies, geographic information systems, digital elevation models, and world-class fire monitoring and management systems. The CFS delivers timely, accurate information on which the Canadian forest sector increasingly depends to ensure access to international trade and markets. The CFS affirms Canada's progress towards sustainable forest management by using the most powerful tool available—reliable information. The CFS is Canada's reporter on national forestry matters.

**The CFS conducts broadly based research.** At any one time, CFS scientists across Canada are developing genetically advanced trees, investigating methods for preserving animal and plant species at risk, modeling the earth's climate and carbon budget, and characterizing secondary manufacturing trends in the economic sector. CFS research is providing support for regulation against alien insect and plant introductions, creating technology for measuring atmospheric ozone, developing forest management strategies that reduce insect damage, and transferring spacial fire management system technology to the United States and other countries around the world.

**The CFS produces award-winning research.** CFS scientists have been recognized for developing ecologically acceptable biological insecticides (Wladimir Smirnoff), for creating DNA marker technology that makes it easier

to catch tree thieves ( Eleanor White), and for perfecting somatic embryogenesis biotechnology applicable to commercial pine species (Krystyna Klimaszewska).

**The CFS conducts research that is national in presence, perspective, and administration.** From research centers located in Fredericton, New Brunswick, Sainte-Foy, Quebec, Sault Ste. Marie, Ontario, Edmonton, Alberta, and Victoria, British Columbia, the CFS delivers its S&T program through 10 national research networks. Each network focuses on an area of science critical to achieving sustainable forest management: forest health, forest biodiversity, forest ecosystem processes, landscape management, pest management methods, the effects of forestry practices, fire management, socioeconomic research, tree biotechnology and advanced genetics, and climate change.

**The CFS is issue-driven and globally focused.** Climate change, intensive forest management, alien pests—all are issues of immediate and pressing importance to Canada and each is directly addressed by CFS research. As the national forest science organization, the CFS is and will remain committed to the national priority that in the 21st century Canada will become and remain the world's "smartest" natural resources steward, developer, user, and exporter. At CFS, forestry research is global research.

In June 1997, Canada's science and technology community, including representatives of government, academia, industry, and research institutes, met under the sponsorship of the Canadian Council of Forest Ministers. Their task was to determine a forest science and technology course of action—a set of priorities for the generation, dissemination, and application of scientific and technical knowledge—that would contribute to achieving sustainable forest development in Canada. The result was the *National Forest Science and Technology Course of Action*,[1] a publication that outlines in seven thematic areas for action directional priorities for the Canadian forest sector to achieve a more coordinated and focused research effort. The seven action areas concentrate on the development of the CFS's capacity in technology transfer, training, communication, and forest management expertise in ways that will advance Canada's ability to meet international environmental commitments and help forest stakeholders gain a deeper understanding of the inherent complexity of Canada's forest ecosystems.

The National Forest S&T Course of Action is an extremely useful framework for communicating the relevance and effectiveness of CFS research as it applies to the current and future needs of forest stakeholders in Canada. *On Course* will present CFS research as it corresponds to the seven thematic areas expressed in the Course of Action. In doing so, it will highlight the extent to which the CFS S&T program responds to Canadian forest policy initiatives and forest sector priorities; at the same time it will provide answers to the difficult biological and operational questions currently facing forest management practitioners.

The seven thematic areas contained in the *National Forest Science and Technology Course of Action* are:

- Forest Science and Technology Management: A Team Approach
- Developing Methodologies for Measuring Indicators for Sustainable Forest Management
- Public Participation: Many Voices
- Forest Ecosystems: Multiple Values
- The Forest Industry: A Global Competitor
- Forest Stewardship: Forest Management Practices
- Aboriginal Peoples: Issues of Relationships

In the sections that follow, the underlying issue of each thematic area is briefly stated, accompanied by an overview of relevant CFS research. As well, each section contains a selection of current experiments and studies. These are narrated by the people best able to explain the significance, relevance, success, and future directions of the CFS—the dedicated scientists and technicians who comprise the Canadian Forest Service S&T program.

[1] Forest Science and Technology Working Group, Canadian Council of Forest Ministers. 1998. Published by Natural Resources Canada, Canadian Forest Service, Ottawa. 17 p. Print and online. [http://NRCan.gc.ca/cfs/proj/sci-tech/action/index_e.html].

1

# Forest Science and Technology Management: A Team Approach

[redacted]

A major challenge for forest S&T identified in the National Forest S&T Course of Action is the need to create better linkages between forest research activities and forest management, processing technology, and product development. If Canada is to remain a world leader in forest resource management, a nationally integrated approach to research is required that will permit the rapid transformation of scientific knowledge into technology, operational tools, and products that are of direct relevance and use to forest managers and other forest stakeholders.

The Course of Action also identified a critical need to enhance awareness about the value and relevance of forest research conducted in Canada. Communicating the benefits that will be realized through investment in forest S&T to senior decision-makers, to other economic sectors, and to Canadians in general is vital. A combination of active marketing of Canada's forest S&T capacity and more effective knowledge and technology transfer is needed if investment in forest research is to translate into full realization of potential benefits. Also required are better mechanisms for measuring the satisfaction of clients and forest stakeholders with respect to the focus, relevance, and usefulness of forest research programs, especially as they relate to solving operational problems.

[redacted]

As the national voice for forest science and policy in Canada, the CFS has actively promoted the development and implementation of a national S&T agenda. CFS continues to seek opportunities for partnership and cooperation in forest science research. The primary purpose of the CFS S&T program is to generate scientific knowledge and innovative environmental tools that promote sustainable forest management and a competitive Canadian forest sector. To fulfil that purpose, CFS has developed and will maintain a world-class capacity to transform forest research results into technical information, models, decision-support tools, and useful technologies that are relevant to the needs of CFS clients and forest stakeholders. Developing technologies that integrate information and support decision-making is a central theme of the CFS S&T program.

To keep Canadians informed on current forest issues, CFS publishes context papers, discussion papers, and strategic plans that present accessible forest science commentary on subjects of critical interest, including alien forest pests, climate change, forest health, biodiversity, and genetic engineering of trees and insects for forest management applications. CFS scientists regularly publish study results in peer-reviewed scientific journals and conference proceedings. The CFS works to make forest research information available to a broad Canadian audience by publishing information in a variety of forms, including reports, technical transfer notes, brochures, botanical and diagnostic field guides, and instructional CD-ROMs. Increasingly, the most accessible source of CFS information is the World Wide Web. Each of the five CFS research centers and the 10 S&T research networks has a Web site where current forest science information, databases, publication lists, research results, research profiles, and links to partner's sites can be accessed. [illegible]

To meet the ever-growing requirement for timely, accurate forest information on a national basis, the CFS is playing a leading role in the development of the National Forest Information System (NFIS). This system will make extensive use of satellite observation, plot-based forest inventory data, and other federal and provincial geographic information to provide a more complete picture of Canada's forest resources and forest ecology. The NFIS will have the latest data-handling technologies

for integrating data sets such as inventories, remotely sensed data, and federal and provincial geographic information into a nationally distributed system. NFIS information will be used for national and provincial planning, strategic decision making, national and international reporting, and assessing the magnitude and impact of environmental change. It will also allow participants to gain more visibility for their information and products.

CFS researchers will also contribute to the development and maintenance of the National Forest Inventory (NFI) database. This is a plot-based system of permanent observational units, which will be put on a national grid of all major forest blocks in Canada. The system will assess and monitor the extent, state, and sustainable development of Canada's forests by providing national data on the status of 25 forest attributes. Stocking, growth, access, number of native and alien plant species in forests, area and severity of visible insect infestation, fire damage, forest disturbance, and wood production will be included. Unlike earlier inventory systems, the NFI will also provide information on attribute trends and changes over time. The first national report containing data collected according to the new design is expected in 2005.

To provide forest stakeholders with a centralized source of information about Canada's forest research expertise, the CFS has developed the Canadian Forestry Researchers Directory(CFRD). Accessible from the World Wide Web, the CFRD provides forest managers and other partners in industry, universities, and government with a direct source of information about the forest research community. For scientists, the CFRD represents a single-point source of information about prospective collaborators, their disciplines and species of interest.

The CFS works to promote technology transfer and commercialization of forest research through the creation of decision-support software, innovative biotechnologies, and operational tools for forest management and monitoring. The CFS actively seeks partnerships and collaborations to further develop and apply these products. Examples include the CanOxy Passive Ozone MonitorPlate™, a reusable apparatus used to measure environmental exposure to ozone, and SEIDAM, an intelligent decision-support system that utilizes geographic information system (GIS) data and advanced image analysis. CFS-developed biotechnologies include a testing procedure for frost hardiness of conifer seedlings and microbiological nonchemical control agents for use against plant species that cause serious reforestation problems.

To foster and promote excellence in forest S&T research in Canada, the CFS, in partnership with organizations such as the Natural Sciences and Engineering Research Council of Canada, or NSERC, and the Social Sciences and Humanities Research Council of Canada, sponsors funding programs specifically oriented to supporting the research efforts of scientists at CFS research centres, graduate students, or those involved in postdoctoral research. These programs bring together researchers from government, universities, and industry who are working towards sustainable forest management.

To promote a framework for a Canada-wide approach to forest ecosystem research, the CFS is coordinating development of the Forest Ecosystem Research Network of Sites (FERNS), a national network of research sites concentrated on the study of sustainable forest management practices and ecosystem processes. Each network site is located in a major Canadian forest ecosystem and conducts long-term, multidisciplinary research into subjects such as harvesting operations, costs, and productivity; forest health; and wildlife habitat. The research programs carried out at each site are multidisciplinary in nature and represent partnerships between universities, provinces, and industry. A specific objective of FERNS is the national and international promotion of Canadian forest management practices.

In developing information and decision-support systems that monitor and predict wildland fire activity in Canada, CFS fire research has greatly enhanced the profile of forest S&T capacity. The Wildland Fire Information System, developed by CFS to monitor wildfire conditions and assist in fire management operations, is also being used in Florida and in Mexico. This system automatically accesses observed and forecast national weather data, displays information as national maps, and disseminates the maps through the World Wide Web. More recently, in partnership with the Canada Centre for Remote Sensing, the CFS has developed Fire M3, a national system that uses satellite technology to automatically monitor, map, and model forest fires across Canada. The system generates maps and fire behavior models that can be easily accessed on the Internet by fire agencies, forest managers, the public,

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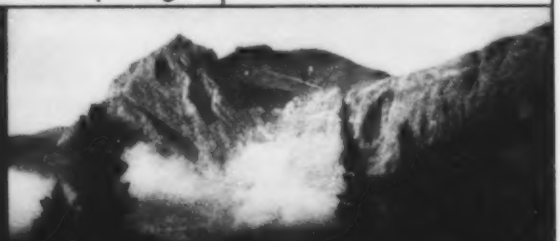
and the media. In 1999, the Fire M3 system received the Agatha Bystram Award for excellence and innovation in the management of information resources and a bronze award for excellence in the management of information and technology in the public sector.

The CFS forest fire science program also contributes to major international, cross-disciplinary investigations into fire and global change, primarily through involvement in the International Geosphere-Biosphere Program (IGBP), the International Boreal Forest Research Association (IBFRA), the United Nations Team of Specialists on Forest Fire, and the International Union of Forest Research Organizations (IUFRO). Production of an interactive training and reference CD-ROM on the Canadian Forest Fire Behavior Prediction System has been instrumental in making many years of forest fire behavior research accessible to various users.

The CFS S&T program is committed to designing, developing, and implementing tools, techniques, and processes that are required to expand Canada's knowledge base in sustainable forest management. In its research programs, the CFS will continue to pursue strategic alliances and to foster a national consensus on forestry issues, thereby ensuring that all stakeholders in the Canadian forest are members of the same team.

## The National Forest Information System: developing a corporate standard for forest science reporting



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Rick Morrison

## The National Forest Information System: developing a corporate standard for forest science reporting

**The objective of the National Forest Information System (NFIS) is to create a forest information infrastructure that will facilitate reporting for policy needs. Scientifically, it will create a standard for collecting and sharing data between users. It is analogous to linking a collection of isolated shops that sell different products in different cities. To harmonize the different data standards and software tools used by each of these shops, there are technical challenges and changes to business practices that must be met. Common identifiers must be adopted for products, and common software tools must be used for core business functions such as inventory and accounts receivable. The problem within many forest science organizations is similar, only their product is forest resource information and the core business functions derive from science and policy drivers. The NFIS infrastructure is the technical glue that will link the information products of the CFS to facilitate access and sharing.**

1

**Even within the CFS, we do not yet have a corporate standard for collecting certain types of scientific data. But to report nationally, we must have one. If information is collected in many different formats and is not widely accessible, it becomes impossible to fulfill our many policy commitments at the national level—obligations for reporting on biodiversity, climate change, and criteria and indicators of sustainable development. Therefore, as part of NFIS we have created a spatial data warehouse that is a distribution and integration layer driven by science and policy needs.**

**Additionally, there are initiatives within NRCan and in interagency government bodies for collecting spatial data and we are trying to connect to those standards. One is the Canadian Geospatial Data Infrastructure, set up by the Inter-agency Committee on Geomatics, with representatives from Health Canada, NRCan, Statistics Canada and so on. They recognize the need for standards for collecting, storing, and accessing spatial data from computer applications. We are trying to follow that standards process in implementing**

NFIS. Also, we want the NFIS to be linked to the ResSources knowledge infrastructure initiative of NRCan as the source of forestry knowledge.

Our work is being driven by science and policy, and we are trying to implement a technical infrastructure they require. Although it is necessary to look at a broad national picture, you can also use NFIS on a smaller scale. A member of the public may be less interested in national maps portraying broad areas than in the locality in which he/she lives and in what is happening in the local forest. The technology NFIS uses will also provide that level of information. —**Rick Morrison**, Senior Systems Scientist, Pacific Forestry Centre. **Development Team:** Doug Bakewell, Brian Low, Rick Morrison, Robin Quenet. **Data Contributors**: Rene Alfaro, Lynn Barnett, Dennis Demarchi, Marvin Eng, Dave Gilbert, Mark Gillis, David Goodenough, Ted Lea, Don Leckie, Sue Martin, Dan McKenney, Bruce Pike, Vince Nealis, Mike Wulder ■

Mark Gillis

## Development, analysis, and reporting of Canada's National Forest Inventory

The National Forest Inventory (NFI) is a national summary of forest resource statistics. It provides data needed by Canada to address policy issues, to meet international commitments, and to develop criteria and indicators of sustainable forest management.

The NFI dates back to the early 1900s. Up until the early 1970s it was compiled from questionnaires sent out to the provinces. The early ones consisted of about 10–15 questions on the forest, its area, volume, and softwood-hardwood mix—rather basic information. The current version of the NFI has existed since 1981 and is a compilation of 48 provincial inventories. New information requirements that have evolved over the last 10 years, however, are making demands on the current NFI that it is not able to respond to. As a result, the Canadian Forest Inventory Committee, the CFS, and the forest industry have collaborated on the design of a new system involving a network of sample plots from across the Canadian landscape.

The collection of basic data will be carried out by remote sensing, primarily aerial photography (about 22 000 plots), with a subsample of ground plots (about 2500). The intent is to sample 1% of the land base. There are large areas of the country not included in current provincial inventories that have not been covered by aerial photography and we will use satelite imagery to capture basic data from these remote areas. We will also use satellite data to confirm that our sample plot distribution is not skewed and to extend the inventory beyond the 1% sample.

2

Until recently the main clients for the information have been our policy groups, who use it for putting together national and international reports. Because we are moving towards a system where we can provide current state of the forest information as well as a picture of change over time, we expect to see our clientele expand. We will also be able to accommodate policy issues such as climate change and forest sustainability and perhaps contribute to some of the biodiversity issues, such as species diversity, forest cover diversity, and change in diversity over time. —**Mark Gillis**, Manager, National Forest Inventory, Pacific Forestry Centre ■

Brenda Callan

## Fungal diseases and pathogen biodiversity: providing information and expertise

An important part of my work at the Pacific Forestry Centre is putting information in the hands of forest managers that helps them diagnose and identify poplar diseases. Interest in the management of poplar for wood products and fiber production is increasing and we need to develop specific regional diagnostic tools that allow informed management decisions and better disease control. One such tool that we produced at the Pacific Forestry Centre is a poster entitled *Common Poplar Diseases*, which helps field workers identify pathogens. More recently, we have published a detailed diagnostic manual of poplar diseases, intended for use by forest managers, pathologists, and diagnosticians. It provides up-to-date common names, photographs of symptoms and damage, detailed microphotographs, distribution maps, and instructions on how to sample for disease.

We also study pathogen biodiversity. I am curator of the largest forest pathology herbarium on the west coast of Canada. The collection houses over 35 000 specimens, representing over 3 300 species of disease-causing fungi. It is an important resource for identifying and confirming suspected diseases. Because it houses many type specimens, which are used as the basis for a species description and for comparison of subsequent samples, the herbarium is of worldwide interest. We maintain two databases: the British Columbia Host–Fungus Index lists fungi known to occur on plants and other substrates and the Herbarium Collections database contains records on 21 000 of our herbarium specimens. Both are accessible from the Pacific Forestry Centre's Web site, so we are a lot more user-friendly than in the old days. No more handwritten accession cards or file cabinets!

—**Brenda Callan**, Mycologist, Pacific Forest Centre ■

## Fire research: extension and application

Although the clients we deal with most often are provincial fire management agencies, we are beginning to do more work directly with forest companies to address the fire-related issues that they raise. We have been developing techniques, tools, and concepts that integrate fire behavior and forest management. For example, we recently offered an instructional course through the University of Alberta that examined the incorporation of concepts relating to fire, especially at the landscape level, directly into forest management planning. Foresters understand forest and timber supply modeling and fire experts understand fire behavior. The course was an attempt to bring the two areas of expertise together to demonstrate that it is possible to adopt long-term management strategies that can mitigate the potential for large wildfires.

We use the phrase "cooling the forest" to describe the concept. We are suggesting that over a period of time, through various actions such as converting strategic areas from coniferous to deciduous species, one can compartmentalize a forest. When fire occurs, instead of covering hundreds of thousands of hectares, its extent can be limited. This has obvious benefits

for wood supply, but it also adds flexibility to forest management and silviculture and allows greater use of prescribed fire for ecological management inputs in other areas. If a forest manager is living with the constant threat of a massive fire covering the landscape and eliminating the entire timber supply, it is difficult to think about anything except getting the wood out.

A somewhat different outreach project I have worked on is the production of a CD-ROM fire training program, funded partly by the province of Alberta. It is based on the Canadian Forest Fire Behavior Prediction System developed by CFS and is intended to supplement training done by provincial agencies. The CD contents include a set of training modules, rules for converting vegetation into fuel types, experimental fire data, drills and practice sessions, and a planning scenario based on an actual wildfire that burned 21 000 ha of forest. The CD is a good example of making our information accessible to those who need it. A significant part of my work is determining the practical extension and application of our research. —**Kelvin Hirsch**, Forest Research Officer, Northern Forestry Centre ▪

## Bryan Lee — Advances in fire science and fire management systems

As a science team, we are fortunate to have a 75-year history of CFS fire science as a basis from which to work. Initially, our work focused on developing tactical fire suppression tools, but today we are more concerned with national fire monitoring and reporting—applications for forecasting climate change, forest sustainability, and other land management issues. My associates and I investigate and model basic relationships between fire, vegetation response, and ecosystem processes at the stand and landscape level.

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We are particularly proud of the national and international acceptance of fire decision support systems developed at CFS, such as the Spatial Fire Management System (SFMS). The system consists of a software program that uses weather, terrain, vegetation, and other data sources to rate fire potential as well as to predict fire occurrence and behavior. To date, SFMS has been implemented in the provinces of British Columbia, Alberta, and Saskatchewan as well as the state of Florida and in Mexico. It will soon find further international application in Southeast Asia, where in collaboration with the Canadian International Development Agency, CFS will provide the advice and technology for setting up the system in Indonesia.

The most recent advance we have made is the Fire Monitoring, Mapping and Modeling System (Fire M3), which allows us to provide daily fire information and statistics on a national scale. Developed in collaboration with the Canada Centre for Remote Sensing, Fire M3 uses satellite imagery and geographic information system technology to create, almost instantaneously, images, maps, model outputs, and statistics describing fire occurrence in Canada. For the first time, we're able to compile daily statistics of area burned, on a national scale. We can now pinpoint where major fires are occurring and translate that information into estimates of area burned. The Fire M3 system improves our national fire reporting, increases the effectiveness of fire monitoring and mapping, and demonstrates Canada's renowned capacity in fire science and management. —**Bryan Lee**, Research Scientist, Northern Forestry Centre ▪

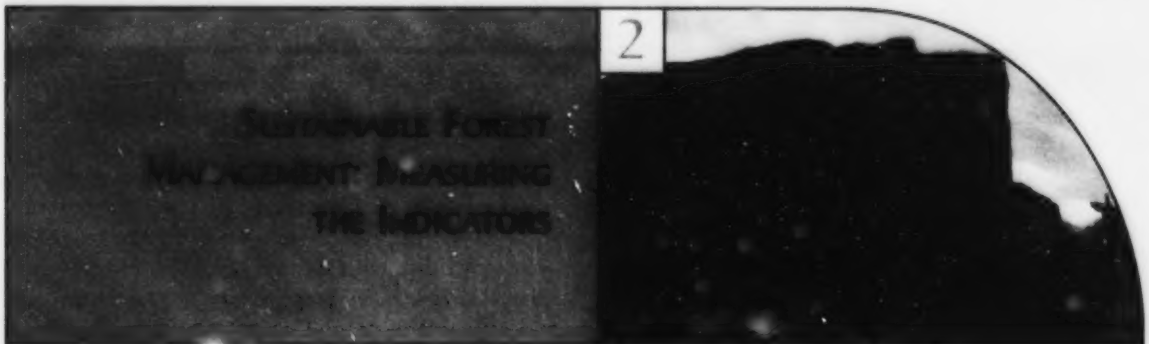
Brian Stocks

## Changes in boreal fire research: from a regional to global perspective

The emphasis in CFS fire research has changed and expanded since the 1980s, when fire research in Canada was carried out primarily for regional clients. At that time, at the Great Lakes Forestry Centre, we focused on our clients in Ontario, although much of the research we carried out did have national applications. We have come to view our research from a broader perspective and as an important area for international cooperation.

Our involvement in global research activities really came about through growth rather than by design. In the late 1980s, we became involved in bringing scientists from other disciplines to some of our test fires to study atmospheric chemistry, smoke products, and other components of those tests. As public awareness of major environmental issues grew, so did collaboration and communication across disciplines, nationally and internationally with scientists in many different organizations. Then, after it had been determined that boreal fire was quite important from a climate change perspective, many more researchers started working with us in the boreal zone in Canada, Russia, and Alaska. Our research has definitely grown and diversified, to an extent that the main emphasis of my work is now global scale biomass burning and its consequences for the global environment.

The projected effect of climate change on the boreal forest is emerging as a major issue in forest research. Canada and Russia together share about 40% of the world's terrestrial carbon. That carbon is at risk if the climate is indeed changing. The effects of climate change are projected to be most significant at northern latitudes, where most of that terrestrial carbon is sitting. Any acceleration of natural forest fire regimes will result in the release of a great deal of carbon. Other countries are going to ask how we in Canada intend to manage it. —**Brian Stocks**, Senior Research Scientist, Great Lakes Forestry Centre ▪



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# Sustainable Forest Management: Measuring the Indicators

Forest management has never been more subject to close and critical scrutiny than it is at present. Increasingly, clear and measurable proof is demanded that Canada's forests are managed in a way that protects conventional forest resources and nontimber values in the present and preserves those same values undiminished for the benefit of future generations. Demonstrating to national and international observers that forest practices are environmentally responsible has become a factor in worldwide market access. Governments, forest sector industries, and all others involved in the activity of managing Canada's forests are now clearly required to demonstrate, using objective and well-defined indicators, that forest management is sustainable.

Canadian initiatives to establish effective means of measuring and reporting on sustainable forest management have taken several forms. A set of criteria and indicators has been established by the Canadian Council of Forest Ministers; forest industries have adopted varying codes of practice; and the Canadian Standards Association has developed a sustainable forest management certification system. However, not all indicators of sustainable forest management can be measured directly, and effective methods for evaluating the impact of management practices on certain nontimber values have not yet been developed. Forests are dynamic and they change with time. Change resulting from management activity must therefore be distinguished from that resulting from natural forest processes. Particular indicators may be effectively measured and recorded at the level of a single forest stand, while others may be continental or even global in their scope. Regardless, more efficient and direct means of obtaining, compiling, and reporting information about forest response to management activities are required if Canada is to successfully demonstrate that its forests are responsibly and sustainably managed.

Research in the CFS S&T program is dedicated to the development of methods, models, and tools that permit better forest measurement and timely reporting of progress and achievement in sustainable forest management. Because forest processes are complex and varied, CFS research often involves collaboration across a wide range of scientific disciplines. Research programs are planned and implemented over varying geographic and temporal scales, most often involving partnership and cooperation with concerned provincial governments, forest industry representatives, and academic institutions. Particular focus has been placed on developing methods for measuring and evaluating biodiversity and forest health and identifying sustainability indicators that are relevant at the appropriate forest, stand, or landscape level. The possible effects of climate change and community impacts on sustainable forest management are also being investigated. Ultimately, research in these areas is directed towards the setting of national standards for gathering and interpreting data. As the national voice and source of expertise in forest science, the CFS is dedicated to providing a national accounting of sustainable forest management for all of Canada.

The CFS has undertaken field studies to characterize the response of forest processes to management interventions, including comparing the regeneration processes of eastern white pine under different management systems, evaluating alternative silvicultural systems in tolerant hardwood ecosystems in Ontario, and modeling postfire forest succession in Quebec mixed balsam fir–white spruce forests. In British Columbia, the Coastal Forest Chronosequence Project has evaluated changes in biodiversity, carbon balance, and nutrient cycle resulting from conversion of old-growth temperate forests to managed forests. In Alberta, the CFS is developing a system for classifying coarse woody debris that will aid in the identification of

rare microhabitats that could be threatened by forestry activities.

CFS researchers are collecting baseline habitat and ecosystem data that will help to identify wildlife species at risk and the forest ecosystems they require for survival. Study of harvesting impacts on old-growth balsam fir forests in Quebec and research into the role of old-growth aspen forest as insect habitat have been completed. In Ontario, research to identify critical indicators of old-growth eastern white pine ecosystems is ongoing. Threatened wildlife populations, including the marten, dependent on old-growth forests in Newfoundland, and bird species such as the red crossbill, closely associated with old-growth forests in Ontario, have been surveyed and the specific forest habitat they require identified. The ecological role of smaller and less obvious fauna, such as arboreal arthropods in coastal and maritime forest ecosystems, is being investigated. In collaboration with the University of Victoria, British Columbia, the CFS has initiated studies of beetle diversity in selected old-growth temperate rain forests.

CFS researchers are developing methods to preserve and protect declining tree species such as red mulberry, butternut, and red spruce. As well, CFS researchers have measured and reported on genetic diversity in species that represent important sources of nontimber forest products, including Canada yew and western yew, and are developing DNA fingerprinting methods for rare plant and insect populations.

To more adequately assess the social, economic, and biological effects of alternative harvesting methods at a larger scale, long-term experiments have been established by CFS researchers, working in collaboration with provincial, industrial, and academic partners. In northern Alberta, Ecosystem Management by Emulating Natural Disturbance (EMEND) is testing innovative harvest methods intended to approximate natural fire disturbance in the boreal forest. Also in Alberta, the Hotchkiss River Project has been established to develop silvicultural techniques that will protect advance regeneration white spruce from blow-down following harvest of the aspen overstory.

In British Columbia, the Montane Alternative Silvicultural Systems (MASS) project has been designed to test alternative silvicultural systems, document operational costs, and study the biological and silvicultural impacts of forest management practices in coastal montane forests. MASS is a multidisciplinary cooperative study involving the CFS, Industry Canada, the British Columbia Ministry of Forests, the Forest Engineering Research Institute of Canada (FERIC), MacMillan Bloedel Limited (now Weyerhaeuser Company Limited), the University of British Columbia and the University of Victoria.

Covering nine separate research sites in Quebec and Ontario, the ECOLEAP project (Extended Concertation for Linking Ecophysiology and Forest Productivity) is aimed at identifying the effects environmental factors have on the growth processes of trees and linking those factors to forest productivity. ECOLEAP is a collaborative effort involving CFS researchers and a network of partners from Canada and other countries. Multidisciplinary studies in remote sensing, mensuration, and ecophysiology and modeling of the factors that control forest ecosystem productivity are being done at the leaf, tree, and plot levels. Ultimately, a predictive model of forest site productivity will be developed, along with a method for applying the model to extensive forest areas.

To gather and measure relevant ecological data at very large scales, such as entire forest landscapes or ecoregions, CFS researchers are currently developing a range of remote-sensing tools and methodologies. Technologies under development include automatic photo-identification of changes to forest boundaries and access roads, the assessment of forest heath from aerial photographs and high-resolution satellite images, the use of airborne scanning lasers to estimate forest stand height, and the application of multispectral digital imagery to detect forest damage due to insects and disease.

At all applicable scales, from local to regional and national, the CFS is involved in research projects that are monitoring, measuring, and reporting the state of Canada's forests. By doing so, the CFS is continuing to provide crucial ecological information, assuring national and international observers that Canada is progressing towards its goal of sustainable forest management.

Tannis Beardmore

## Seed storage and conservation: preserving biodiversity

One way of preserving a species of tree that is threatened or endangered is to conserve its seed. Butternut is threatened throughout its range by butternut canker. The disease is always fatal once a tree is infected. Unfortunately, in the case of butternut, the solution is not as simple as just collecting the seed and storing it until the disease problem can be controlled or eliminated. Seeds fall into two categories, orthodox and recalcitrant. Orthodox seed can be stored for long periods of time, even 50 years. Recalcitrant seed lacks any tolerance for drying or storage. Butternut seed is recalcitrant. After 2 or 3 years of storage, the seed is completely nonviable.

To conserve butternut seed we initially used conventional storage techniques such as mason jars. We are now using a new apparatus, a piece of plastic piping called an invigoration tube. It has seals at each end that permit air movement and prevent condensation, while maintaining a high water content in the seed. These tubes have extended by about one year the time that butternut seed will remain viable. This extension has allowed us to investigate a different technique, cryogenic preservation of the seed's embryonic axis. When seed is collected directly from a tree or right after it is shed, the embryo will not tolerate exposure to liquid nitrogen, part of the cryogenic preservation process. But if we store the seed whole for 12 months in an invigoration tube, and then excise and cryogenically preserve the embryo, we see a higher tolerance for exposure to liquid nitrogen. After 4 months in deep freeze the embryos still germinate and form viable seedlings.

We are also studying the physiology of the seeds of red maple and silver maple seeds. Although these species are so closely related that they can be crossed to produce hybrids, red maple produces orthodox seed and silver maple recalcitrant seed. Abscisic acid, a plant hormone that promotes leaf detachment and inhibits germination, may account for the difference. Our research shows that in silver maple seed, the abscisic acid content is high but rapidly declines just before the seed is shed, while in red maple seed it remains high up to the time the seed is shed. By applying a growth retardant to the seed of silver maple, we can maintain the high abscisic acid content; after that it will tolerate drying. But the seed will only respond to the growth retardant at a critical time in its development. We are now trying to identify exactly when that critical period occurs, as it differs from one year to the next. —**Tannis Beardmore**, Research Scientist, Atlantic Forestry Centre ■

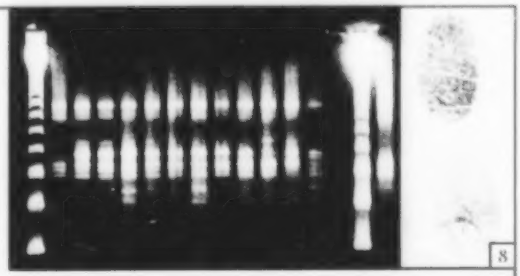
Linda DeVerno

## DNA techniques for monitoring biodiversity and genetic stability

DNA from forest trees, insects, and fungi can be used to monitor biodiversity and to assess the effects of forest management processes on ecosystems, species, and genes. A technique called DNA electrophoresis enables us to produce a picture of the genetic fingerprint of an organism. These genetic fingerprints help us to distinguish between closely related species and to even identify hybrids of species that are not supposed to exist in nature. For example, a CFS entomologist brought us some budworms that did not match the traditional forms of jack pine budworm or spruce budworm (eastern). On examining the DNA from the budworms, we found that it had characteristics of both species, meaning the budworms had to be hybrids. Although jack pine budworm and spruce budworm could be crossed in a laboratory, scientists had always thought that crossings did not occur in nature. Since then we have analyzed DNA from museum specimens; evidently, budworm hybrids have existed in nature since at least

1943. We've also shown that even DNA from dead and desiccated organisms can be used to track what has happened in nature over time.

Under my supervision, Kevin Burgess, a Master's student at the University of Guelph, Guelph, Ontario, has been trained to use this DNA fingerprinting technique to identify red mulberry, a native tree species considered to be at risk in Canada. As a result of hybridization with white mulberry, which was introduced from Asia in the mid-19th century, pure red mulberry has become extremely rare. Only six populations remain in Canada. We hope to determine whether the remaining Canadian populations growing at the northern limit of the species range have unique genetic features. It's a problem similar to that of the budworm. In the field, you can't tell the species and the hybrids apart. We will use DNA from herbarium specimens collected before white mulberry was introduced into Canada to establish a genetic reference for the native species.



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With fellow researcher Y.S. Park, I have also used DNA to assess the genetic stability of cryogenically preserved conifer clones and to verify that somatic embryogenic clone lines of pine species are composed of a single genotype, rather than multiple genotypes. As well, these DNA techniques are being used to identify native versus introduced plant quarantine fungi and alien beetles. —**Linda DeVerno**, Molecular Biologist, Atlantic Forestry Centre ▪

Christian Hébert

## Measurement and conservation of forest arthropod biodiversity

The first criteria for sustainable development is conservation of biological diversity. The animal species listed as endangered, vulnerable, or threatened in Canada are almost all vertebrates, yet the diversity of insect species in forests is much greater than that of vertebrates. I am developing tools and strategies for monitoring the biodiversity of forest arthropods—insects and related invertebrates.

One of my studies, conducted in collaboration with Laval University, Québec City, and the Quebec Ministry of Natural Resources, measures the impact of forest practices on insect communities. We have been comparing beetle populations in merchantable balsam fir stands harvested 50 years ago with populations found in old-growth balsam fir stands of about 100 years old. The comparison gives us a picture of the effects of habitat modification, an important biodiversity issue. We need to track a species' range over time to obtain a true picture of how it is affected by forestry practices. Old-growth forests are important in developing conservation strategies for biodiversity. I hope that the data we are collecting will

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contribute to a better understanding of the scientific value of these forests.

We are also trying to characterize the arthropod community in old-growth balsam fir forests on Anticosti Island in the St. Lawrence River. But selective browsing of young balsam fir and deciduous species by white-tailed deer, a species introduced to the island

a century ago, has been steadily altering the forest. Along with la Société des établissements de plein air du Québec (SEPAQ) and the Quebec Department of Parks and Fauna, I am involved in a project to enclose a 1-km$^2$ area on the island with light polypropylene fencing. By keeping the deer out and thus eliminating overgrazing, we expect to see a rapid change in this forest area, including more ground vegetation, lower soil temperatures, greater soil humidity, and an increase in insects and fungi. We want to measure the extent to which we can restore biodiversity in this type of damaged and deteriorated forest.

In conjunction with researchers across the country, we are also endeavoring to create a national database for existing insect collections. A great number of specimens are stored throughout the country. These collections are really datasets. We have much reference data, but it is "sleeping" in our collections. With a database management system, such as the one developed at the University of Québec in Chicoutimi, we will be better able to determine which insect species now live in reduced areas of distribution. —**Christian Hébert**, Entomologist, Laurentian Forestry Centre ■

Ian Thompson

## Contributions of old-growth eastern white pine to regional biodiversity

Because eastern white pine is the largest tree species found in eastern North America and one of the longest living, it creates a unique structure for forest wildlife. When viewed from above, a white pine forest looks much like a green carpet interwoven with maple, spruce, or beech trees, with the big white pines towering far above. It is atypical of other forest types such as those in the boreal forest, where trees tend to be similar in height and in age. The old-growth phase of a white pine forest, where total biomass accumulation in the forest is actually declining, can last as long as 120 years—through multiple fire cycles and complete species changes in the sub-canopy. What we want to ascertain is the contribution these older forest types make to total biodiversity in the landscape.

My research focuses on identifying distinct guilds of organisms that specifically use the structure of an old-growth forest. We have found that a group of bat species in Ontario that selectively forage in white pine stands seem to be good indicators of a forest in the old-growth phase. Many of the bat species breed in colonies inside trees. They require a forest of a particular age structure and with a particular woodpecker population to create nesting sites for them. Then all the insects the bats feed on have to be present in sufficient numbers for the bats to breed. The super-canopy the white pines create is crucial to the relationship. Some of the bats we are studying are rather large and clumsy and are not able to forage in among dense branches in the lower canopy. But as the spacing between the white pines is quite wide, the larger bats can cruise above the canopy while hunting for insects.

We are also attempting the difficult task of documenting the history and premanagement structure of the vast old-growth pine forests that once stood in eastern Canada. Historical land survey records exist, but white pine may have been under-represented by surveyors of the time. Their method was to walk through the forest recording the species around them

and they probably missed many of the big white pines because their branches were too far overhead to be noticed. We can measure the frequency of white pine stumps in logged-over areas if there has not been ground fire. Some white pine stands that have never been logged do remain and these can be compared with others in the landscape. In this type of research, we almost need to be historians as well as landscape ecologists.

A key application of this research will be the development of models that will predict the presence of species based on forest type. This will allow recommendations to be made as to the amount of old forest necessary to maintain biodiversity and how existing stands might be better managed to retain the biodiversity they contain. The information we can provide to the forest industry will help them to maintain the functional relationship between forest processes and animal populations. —**Ian Thompson**, Forest Wildlife Ecologist, Great Lakes Forestry Centre ■

François Gougeon

## Delineating tree crowns with high-resolution multispectral images

The computerized forest information and monitoring system that I am developing with fellow researcher Don Leckie *can* tell the forest from the trees. The system uses remotely gathered, high-resolution multispectral images of forest areas as a data source; this enables us to pick out individual tree crowns, classify tree crowns into species, and regroup species into forest stands. The process focuses on the particular way in which shadows are distributed between tree crowns in a typical medium-to-high-density forest. It follows the valley of shade between the tree crowns, then uses a rule-based algorithm to delineate the tree crowns. The system is not yet fully automated; it still requires an interpreter to point out areas containing a single tree species, or even individual trees, as examples from which digital signatures are generated. The signatures are then classified and the whole image is processed.

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Once we have individual tree crowns, we can also generate thematic images that allow us to quantify statistics on canopy closure, gap density, the distribution of gap sizes, and tree distribution compared with other stands. Because all the images are linked to a geographic position, we can determine the location of each tree. We have also used the system to analyze regeneration in forest plantations. Our analysis techniques differ slightly for plantations, but we have been fairly successful in determining seedling density and stocking values.

The use of multispectral images allows us to generate colors in images that help interpreters with tree recognition—each species can be assigned a different color. When we compare the classification generated from our system with actual species sampling on the same stands, we are incorrect often by only 10%–20%. In future, we will continue to develop the system and make it much more intelligent. At present it relies on color, really the multispectral image within the tree crown, to recognize species. We want the system to emulate more closely the way human photo-interpreters work and to use texture, or the structure of the crown, to recognize the species. —**François Gougeon**, Image Analyst and Research Scientist, Pacific Forestry Centre ■

Dan McKenney

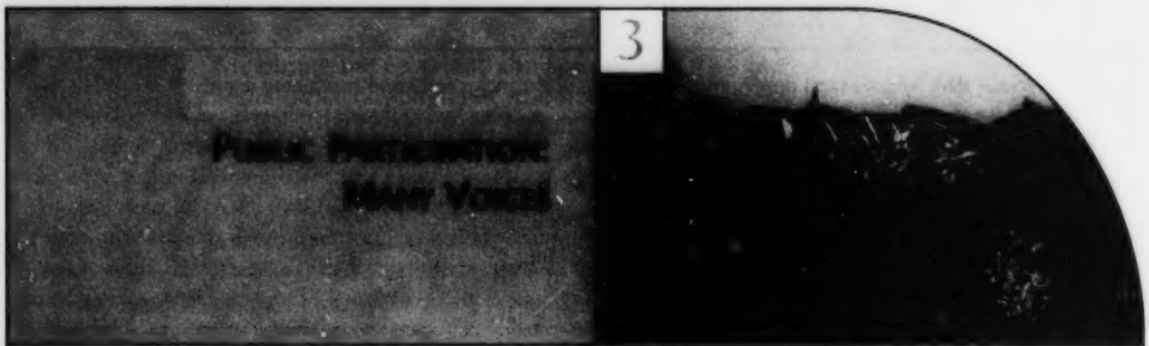
## Developing spatial landscape models to address management and policy questions

What we really do is develop data, tools, and approaches aimed at answering management and policy questions at the landscape scale—tools for making better informed decisions about biodiversity, conservation, and climate change. We use various types of data and geographic information systems (GIS) to build spatial models, but we are really trying to better understand the spatial variation inherent in species distribution, abundance, and productivity. All of the conflicts about resource use revolve around these topics.

One of the most successful data sets we have yet produced is the national digital elevation model. It is a computerized grid of latitude, longitude, and elevation applicable to the mapping and analysis of data types, including past and present climate across Canada. The climate models give us the capacity to take biological data sets, for example, yearly insect damage or vegetation surveys, and append climate variables to them. We also try to incorporate remote-sensing data, which gives us the ability to analyze distributions over very large areas, in relation to climate, vegetation structures, and other factors. We have completed applications relating to birds, moose, reptiles and amphibians, and tree diseases.

Tools that provide a spatial view of the landscape permit better appreciation of the trade-offs required in resource management decisions. A kind of trade-off analysis is required to manage timber at a local scale while making strategic decisions about the landscape at a much larger scale—the boundary for timber in a stand is not necessarily the boundary for a particular wildlife species. We need to know where the most important parts of the landscape are for protecting a species and for growing trees. If forest managers are able to identify the important parts of the landscape for a particular value, they can then interact with biologists and wildlife managers to develop harvesting plans that ensure sufficient suitable habitat exists in the landscape.

Many resource concepts are abstract and complex. Habitat itself, the particular way humans view a species' relationship with the environment, is an abstract concept. We are trying to develop a basic set of primary data that enables ecologists, foresters, and land managers not only to explore these concepts but also to visualize them. Climate, soil, topography, and current vegetation are the main concerns. It can be mind-boggling to keep all the information in context, but because of computers and GIS we are better able to do so than ever before. If someone comes to us with a concern about a species, we have the capacity to make observations, do some analysis, and produce a map. The map might never have been seen before and it may well raise other questions, but it is a tool that we did not have previously. —**Dan McKenney**, Chief, Landscape Analysis and Applications, Great Lakes Forestry Centre ■



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# Public Participation: Many Voices

One Canadian in sixteen either directly on indirectly earns a living from the Canadian forest. Ninety-four percent of forested land in Canada is publicly owned, crown land. To a great extent, the history of Canada is the history of our society's evolving relation with the forest, from exploration and exploitation to sustainable management and, finally, to sustainable development and global stewardship. When it comes to forest resources, all Canadians are economic stakeholders.

It is not surprising, therefore, that many voices are now heard that seek to directly participate in the shaping of decisions affecting forest resource allocation and utilization. Classical approaches to forest resource management remain relevant, but there is a new imperative for a more diverse perspective in viewing forest economic development, a perspective that includes traditional Aboriginal and community-based values. In the past, forest economics research has focused on employment, market development, export opportunities, and the creation of conditions necessary for economic stability. Such research is and will continue to be vital to characterize this dynamic and complex sector of the Canadian economy. But as demands grow and opportunities diversify, a more complete picture of the economic contributions of nonconsumptive forest values, such as tourism, recreation, and traditional subsistence, will be required. Greater consideration of the human element in forestry is needed.

For all concerned, increased emphasis on balancing diverse social interests while maintaining the economic and biological health of a vital part of the Canadian economy has greatly increased the complexity of managing forest resources. Methods of assessing the social effects of forest management plans must be improved and better avenues for public consultation and conflict resolution are needed.

CFS socioeconomic research is focused on community sustainability, nontimber forest values, socioeconomic analyses of forest management, and assessment of competitiveness in international markets. Research is directed in large part to the development of tools for measuring public concerns and attitudes towards resource management. A principal area of investigation is the development of criteria and indicators for sustainable forest management in partnership with the Canadian Model Forest Program and model forest sites throughout Canada. Model forests are particularly appropriate forums for socioeconomic research as participants in the program have direct interest and influence over the uses in the forest. A national project focusing on local socioeconomic indicators of sustainable forest management is planned.

CFS researchers are conducting a study at the Foothills Model Forest in Alberta to learn more about public values with respect to the forest and public perceptions of forest management in Alberta. The project is developing standardized measurement methods that can be applied to stakeholder groups and populations across the country.

In Quebec, the CFS and the Quebec Department of Natural Resources have collaborated on a study of the province's forestry workforce that includes demographic profiles and information on productivity, wages, working conditions, and additional sources of income for individuals working in the forest management sector. A second part of the survey, conducted in 1999, included questions on qualitative issues such as job satisfaction, occupational safety, and training.

In New Brunswick, a research program has been developed that focuses on the linkages between forestry and rural development. Results will be documented in

a report that outlines rural development forestry issues and recommendations for future research. The report will be followed by an evaluation of value-added forestry initiatives in Atlantic Canada. Another study maps social indicators of community sustainability. It involves transforming Statistics Canada census data into easily read charts, graphs, and histograms and then placing them on a Web browser along with other socio-economic data related to dependence on the forest. Studies focusing on resource-dependent communities in rural Canada are also ongoing, as is research into natural resource accounting and mechanisms for integrating management planning objectives across land tenures.

To gain insight into economic factors that relate to nonconsumptive forest use, CFS researchers have carried out detailed studies of visitor-based employment and ecotourism in resource-dependent communities. Other studies, including the determination of public attitudes towards sustainable forest management, investigation into the impact of forest harvesting on recreational hunting, and assessment of attitudes of recreation enthusiasts towards forest management, have contributed to the development of models that link public attitudes with economic-choice behavior. As well, a Community Development Impact Model developed in cooperation with CFS researchers has been used in Northern Ontario to measure economic impacts affecting the forest sector. It accurately estimated job losses resulting from recent industry cutbacks.

In cooperation with the Finnish Forest Research Institute and the University of Helsinki's Department of Forest Economics, CFS researchers have contributed to studies measuring human values and preferences related to biodiversity, producing results directly applicable to conservation decision making. CFS researchers have also participated in the analysis of forest policy in the major softwood-producing regions of the world and are investigating the competitiveness of British Columbia forest products in the Japanese market. A review of the economic, social, and environmental impacts of alien pest introductions in Canada has been initiated. Research carried out in collaboration with the Government of Alberta intended to assess the cost-effectiveness of pest-control strategies has positively affected forest management in that province. In collaboration with the University of Alberta, Edmonton, the CFS has conducted a study of the socioeconomic impacts and adaptive responses to climate change. As well, CFS participation in Social Sciences and Humanities Research Council of Canada funding programs has created new opportunities for graduate students to undertake socioeconomic research on a variety of fronts.

Future socioeconomic research will continue to focus on the development of criteria and indicators of sustainable forest management and First Nations issues, particularly the integration of traditional knowledge into forest management. In addition, research into the dependence and stability of forest resource communities, analysis of value-added opportunities, and small-scale and private lands forestry will receive attention. Investigation into socioeconomic factors of climate change, including the economics of carbon budgets and examination of uncertainty in models of carbon sequestration in northern boreal forests, is also planned.

At present, many voices seek to be heard. Many Canadians seek to participate in decisions affecting forests and to benefit from the resources they contain. By focusing on the human aspect of forest management and economics, CFS researchers are developing knowledge, models, and tools that will permit the voices of Canadians to be heard and the concerns expressed to be addressed.

Peter Boxall

## Measuring the economic and social significance of nontimber resources

One problem we face in socioeconomics is a lack of models and data. This has inspired me to focus my research on developing models while generating data. Along with fellow CFS colleagues and researchers from the Sustainable Forest Management Network Centre of Excellence, Edmonton, I research nontimber values, particularly nontimber goods and services, and estimate prices for them. There are many significant benefits from the forest that do not necessarily show up in the gross domestic product.

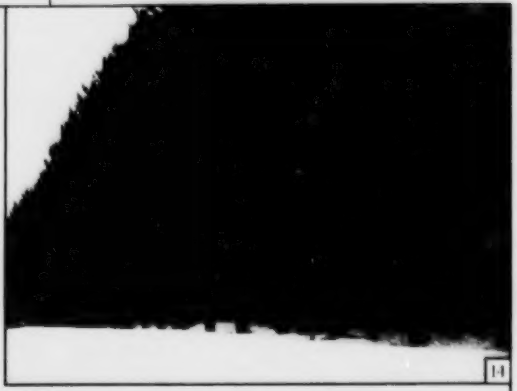
Early in our research, we concentrated on existing information that could be used to develop models and to determine values. Lately, however, we have looked at the more intangible biodiversity issues, especially those involving trade-offs between job creation or loss and the preservation of threatened species, such as grizzly bears. I work closely with forest scientists and wildlife biologists because in the case of nontimber values such as grizzly bears we have to understand how forestry practices affect a bear population as well as how much a decision to maintain that bear population will cost. This often involves tradeoffs: what sacrifices are people willing to make to have nontimber values and are there ways of minimizing these sacrifices?

We designed several projects to measure nontimber values. One involved wilderness canoeing in a provincial park in the Canadian Shield region. Canoeists "consume" a forest value as they paddle by. Using a registration system, we recorded information on where the canoeists did or did not go. We used the information to create models that predicted route choices. By linking the routes to field work and forest inventory information, we found that the canoeists preferred mature jack pine to mature black spruce ecosystems. The former are easier to camp in and have fewer mosquitoes. Although the canoeists did not like to travel through previously burned areas, they enjoyed areas with cut-blocks behind the forest buffers along a river. Cut-blocks are smaller than burnt areas and make good moose habitat, increasing the likelihood of seeing a moose. In another study, we took photographs of forest scenes and developed a regression model based on how people rated the visual characteristics of the photos. It shows that people rated forest stands with insect damage as unappealing, whether or not they actually knew the damage was from insects.

From our studies we can create an ideal forest for a canoeist: it would have extensive mature jack pine ecosystems and a few cut-blocks, and fire and insects would be suppressed. We now have a model that links canoeing back to harvesting, to forest ecosystems, to fire, and then indirectly to wildlife habitat. However, a moose hunter would probably want a different type of forest. The challenge in the above cases would be to practise forestry while not affecting (or at least minimizing and better yet enhancing) hunting and canoeing values. For a forest manager, this means integrating these demands on the forests with timber extraction; for an economist, maximizing the net present value of the forest, which includes all of its uses. —**Peter Boxall,** Non-Timber Valuation Economist, Northern Forestry Centre ■

Bill Wilson

## Forest economics research: constructive answers to difficult questions



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Forest economics is an area that is sometimes overlooked, unfortunately. Economic policy and contributions such as employment and net export earnings are key ingredients to meeting the fundamental challenges we face in forestry. The people who control research funds think in terms of economics, for example, jobs and exports. In addition, the forest issues we are dealing with now, and may expect to see in the future, are based largely on economic factors and economic conditions. Efforts to more effectively integrate natural sciences into the policy world are past due. Many issues in the forest sector have an inherent interface between the natural sciences and economics.

In our research, we seek to provide constructive answers to difficult questions. We try to examine, comprehend, and summarize the future physical and financial environment of forestry in Canada and in other countries. What, for example, will be the effects in Canada of the coming transition from harvesting existing forests—the natural endowment—to commercial forestry and operating in a regime of intensive forest management and heavy capital loads? In the next cycle, we will have to invest in growing trees. Given the time it takes to grow a tree to economic maturity in Canada, that is going to be problematic. Growing trees is capital-intensive, risky, and ties up capital for a very long time, which people often don't realize. We must consider the problem from at least three perspectives—social and community considerations, financial considerations, and physical considerations. We have already investigated the financial and physical aspects of transition, that is, looking into the economics of silviculture, the methodologies by which we make the change to intensive forestry, and how the necessary capital is to be raised in equity markets.

We conduct studies into industry, trade, and forest economics issues. In partnership with companies and provincial agencies, we have done a fair amount of research on secondary manufacturing, which is a high priority area both in the forestry sector and in government. We also take part in projects that are multidisciplinary. We are currently examining the potential economic effects of alien pest introductions. Increased international trade has led to alien pests arriving in shipments to Canada. Some of these alien species may migrate to the forest and find a sustainable ecological niche, which would have social, political, and economic significance. For example, some evidence suggests that in the United States, the introduced Formosa termite is responsible for steel becoming a substitute for wood in many affected areas. —**Bill Wilson**, Director, Industry, Trade and Economics, Pacific Forestry Centre ■

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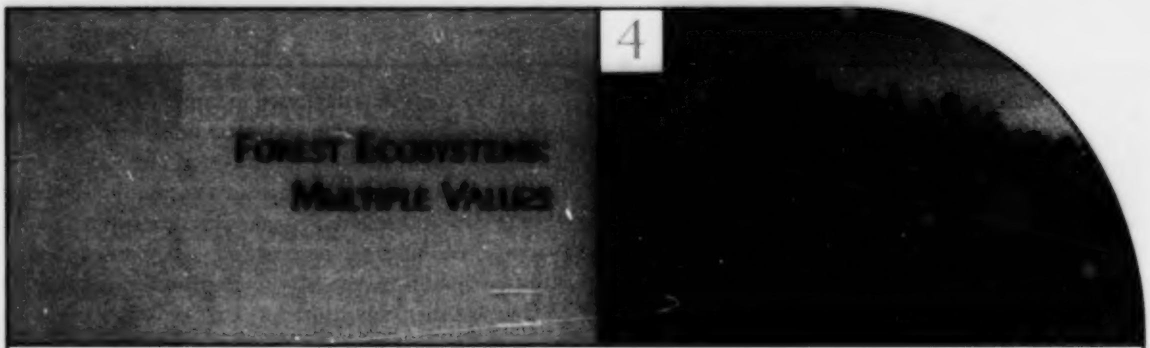
# Forest Ecosystems: Multiple Values



Forest management has evolved into an activity that involves a great deal more than simply regulating wood supply. Fiber production is just one part of a complex interconnected activity that is equally concerned with protecting the environment and integrating forest management into a wide range of land-use objectives. New adaptive silvicultural approaches, including harvesting methods that mimic natural fire disturbance, are being developed and continuously modified as quantitative information becomes available. The shift to ecologically based forest management demands of forest managers an expanded working knowledge of forest processes. The question has been raised as to whether current forest research is sufficiently broad in design to measure a range of forest ecosystem responses to natural disturbance and a variety of forest management interventions. Is forest research too narrowly focused on operational aspects of forest management? Does it sufficiently consider other forest-based activities and nontimber forest values?

Adding to the complexity are Canada's obligations under international agreement to implement actions and fulfil reporting requirements respecting climate change and biological diversity. These obligations require accurate and timely forest ecosystem data appropriate to a range of ecological scales, ranging from local forest plots to broad national landscapes. Anticipating the possible effect of climate change at northern latitudes and determining the global impact of Canada's forest sector activities on carbon cycles and biodiversity present even greater challenges. Long-term systematic research and basic inventory work that provides benchmark data relating to biological diversity, land cover, and forest processes are as vital as applied, outcome-oriented research.

The CFS S&T program is focused on the development of statistical tools and predictive models that will enhance the CFS's existing capability to determine when significant changes are occurring in forest ecosystems. This will allow forest managers to anticipate and mitigate negative environmental effects resulting from insect infestations, fire, climate change, and forestry activities, including alternative harvesting. CFS researchers are using leading-edge remote sensing and geographical information systems (GIS) technology to provide ecological information on scales ranging from an individual tree leaf to entire ecoregions. The recently completed Land Cover of Canada Map, developed by researchers from the CFS and the Canada Centre for Remote Sensing, depicts the entire Canadian land mass. The map, generated from high-resolution satellite imagery, includes 29 different land cover types and 12 different classes of forest.

CFS Advanced Forest Technologies experts, in partnership with the Canadian Space Agency, are contributing to Earth Observation for Sustainable Development of Forests (EOSD). The EOSD program will employ satellite-borne remote-sensing technology to gather, quantify, and distribute forest data and will directly assist Canada in meeting international sustainable forest development commitments. Other satellite-imaging initiatives include the use of Landsat satellite images to map the location and spacial distribution of conifer understory in hardwood forests, automated interpretation of multispectral satellite imagery to assess forest health, and the development of classification methodologies to utilize satellite images in forest mapping. As well, the feasibility of employing high-resolution imagery to detect root disease in forest trees has been demonstrated.

To better measure forest ecosystem sensitivity to climate change, CFS research is aimed at enhancing measurement and prediction capabilities. Long-term research projects have been established to investigate climate change related aspen decline, to produce carbon

budget models, and to develop and refine a Canadian regional climate model. The Canadian Intersite Decomposition Experiment (CIDET), a cooperative effort of researchers from the CFS, universities, and provincial ministries, is investigating long-term rates of litter decomposition over a broad range of forested ecoclimatic regions in Canada. This is being undertaken in part to provide data on the role climate may play in rate of forest litter decomposition. CFS researchers are contributing nationally to projects such as Boreal Ecosystem Research and Monitoring Sites (BERMS) and internationally to the International Geosphere-Biosphere Programme (IGBP), the Boreal Forest Transect Case Study (BFTCS), and the Intergovernmental Panel on Climate Change (IPCC).

CFS researchers are developing databases on the population ecology of forest insects, fungi, and microorganisms that include detailed information relating to behavior, natural enemies, and life cycle patterns. One study concerns the identification of insects and microbes that could serve as indicators of ecological change and the quantification of their contribution to the global carbon budget. A national information database for archiving this type of research data is currently planned.

The increasing introduction into Canada of alien (also referred to as introduced, nonindigenous, nonnative, or exotic) insects and diseases that attack trees represents a major threat to natural ecosystem heath and stability. Past introductions of diseases such as Dutch elm disease, chestnut blight, and white pine blister have radically altered North American forests and the biodiversity they contain. At present, growth in global trade and the movement of goods has increased the rate of destructive pest interception in Canadian ports, and pests such as the Asian long-horned beetle and pine shoot beetle have the potential to inflict severe damage on both commercial and noncommercial forests. CFS researchers are responding to this threat by developing monitoring methodologies that will provide basic data in support of regulations that will serve to limit pest introductions.

CFS research is dedicated to improving methods of controlling vegetation and insect pests, with special emphasis on developing nonchemical alternatives to herbicides and pesticides. Increased restrictions on the use of chemicals in forests, particularly near streams and other environmentally sensitive areas, have intensified the search for viable vegetation management alternatives. CFS researchers have contributed by developing, assessing, and registering a wide range of nonchemical biological control products, for use in reforested areas and tree plantations. Mycoherbicides such as *Chondrostereum purpureum* and *Fusarium avenaceum* have been developed as alternatives to chemical herbicides for controlling vegetation. Research continues into the use of snow molds and rhizobacteria as natural control agents against the invasive species bluejoint grass. Other studies are evaluating the potential of naturally occurring fungal parasites to control dwarf mistletoes, parasitic plants. Biocontrol agents for use against white pine blister rust and annosus root and butt rot are being developed, as are DNA detection methodologies for early identification of scleroderris canker.

The CFS will continue to provide scientific expertise and a commitment to long-term ecological research by assessing the impacts of forest management practices on genetic diversity and the genetic response of tree species to climate change. Ongoing CFS research to develop carbon budget models of Canada's forests and to assess the role fire plays in global carbon cycling will directly add to our understanding of and ability to predict climate change. The CFS will continue its research to determine the effects that climate change may have on the fire cycle in west-central Canada and on fire frequency in boreal forests. By developing a better understanding of the fundamentals of forest ecosystems, CFS research is providing forest managers and policy-makers with timely precise information to report on the current state of forest resources at a national level and to forecast change in forest ecosystems arising from human and natural disturbances.

Ian Campbell

## Past and future climates: anticipating the boreal forest's response to global change

Many scientists think that the climate under global warming will be similar to the climate of a warm period 6 000 years ago. Together with CFS colleagues and researchers from the University of Alberta, Edmonton, I am examining the paleo-record, using a variety of techniques, including study of fossilized pollen, to get a picture of what the western boreal forest looked like at the time.

One of our pollen sources is sediment from Pine Lake near Red Deer, Alberta. The lake is located at the aspen parkland–grassland ecotone. Ecotones are the boundaries between regions. We need to know what controls the locations of ecotones and how these ecotones might move or change character as a result of climate change. We believe that the Pine Lake area was once open grassland, with clumps of aspen restricted to north-facing sites. Today, despite widespread land clearing for agriculture, there is now more aspen in the area than existed in prehistoric times. Pollen contained in the lake sediments tell us that between 1880 and 1900 there was an explosion in the aspen population. This explosion coincides with the demise of the bison. Until late in the 19th century, bison were present in the area in great numbers. They prevented formation of an aspen forest by eating or trampling most of the aspen shoots that grew from root sprouts after prairies fires.

This event raises some interesting questions. Aspen forest can function as a nurse crop, meaning that it can nurture another tree crop by protecting it from the elements. Will other tree species move into the area and start spreading? Anecdotal evidence suggests that spruce may be establishing under the aspen canopy in some areas. Also, will the aspen continue to spread farther south over time? Generally, climate change suggests warmer and drier conditions and migration of species northward. But here aspen is actually moving southward because the grazing pressure from bison has been removed. We do not yet know whether the effects of warming in this area will counteract the southward movement.

The diameter of the silt grains in the Pine Lake sediment also tells us about the climate in which the paleovegetation grew. We hypothesize that in dry years, water flowed slowly through the lake, allowing fine silt particles to accumulate on the bottom. In wet years, water flow was faster, and only coarse material could settle out. The resulting contrast between fine and coarse silt is a very good indirect indicator of past climate. Because the record is 4 000 years old, it is possible to carry out statistical modeling. We have found a 1 500-year climate cycle that suggests the earth is already in a natural period of global warming. This does not mean that carbon dioxide and other greenhouse gasses are not the major causes of the present trend; it suggests that some of our predictions based solely on greenhouse gas warming could be too conservative. The warming could be more rapid and more severe than expected. —**Ian Campbell**, Climate Change Modeling Scientist, Northern Forestry Centre ▪

Ted Hogg

## Climate change and the western boreal forest

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Will forests at the dry southern edge of the western boreal forest continue to exist under a warming climate? To answer this and other climate change questions, biologist Rick Hurdle and I have established a study area in the drought-stressed aspen parkland of Batoche National Historic Park in Saskatchewan. The climate there is similar to that predicted for the boreal forest under climate change. We hope to learn about the processes that might limit forest productivity under a predicted drier climate. We have conducted process studies—measurement of temperature, air humidity, and simultaneous water vapor release from the forest. Over long time periods in these forests, the role of disturbance becomes critical. In the case of aspen, forest tent caterpillar is a major disturbance. We believe that repeated defoliation by forest tent caterpillar coupled with extreme weather events can cause aspen decline.

Through involvement in collaborative research within the Boreal Ecosystem Atmosphere Study (BOREAS) and the Canadian-led follow-on study Boreal Ecosystem Research and Monitoring Sites (BERMS), I became aware of the need to study the effect that forests may have on regional climate. We have looked at water vapor release from aspen forests by measuring individual trees on the ground and whole stands from towers suspended above the forest canopy. What we are seeing is that before leafing out in spring, the amount of water coming off an aspen forest is extremely low, around 0.5 mm/day. Over a period of a week or two, as leafing out occurs, that figure increases 10 times. This happens across the entire landscape. What effect does this have on climate? It may be sufficiently significant to start the rainy season in this part of the world. Temperature may also be affected. After leaf out we generally see cooler temperatures than we would expect if the aspens were not there. In many cases forest may have a greater affect on regional temperature and precipitation than climate change has on forests.

Changes to the composition of forests, for whatever reason, might well cause climatic feedbacks. It is not just an issue of whether there are trees on the landscape, but the kind of trees they are. When you measure the water vapor released by a conifer in spring, it is only about half that released by an aspen. Something we do know from other parts of the world is that complete loss of forest cover can result in desertification. **Ted Hogg**, Research Scientist, Northern Forestry Centre ■

Pat Bodnar

## Remotely sensed airborne and spaceborne data: new methods of extracting information

The CFS's Advanced Forest Technologies (AFT), Methods and Systems Group, of which I am a part, is headed by David G. Goodenough. It was established in 1991 when Dr. Goodenough and other national and international collaborators were sponsored under the NASA Applied Information Systems Research Program to develop a System of Experts for Intelligent Data Management (SEIDAM). Our group now conducts research into several key technologies, including geographic information systems, remote-sensing technologies, databases, multimedia re-visualization, and modeling. All of these technologies fall within the context of artificial intelligence.

We are now involved in a new project—Earth Observation for Sustainable Development of Forests (EOSD), a 10-year initiative supported by the Canadian Space Agency and the CFS. This project will use satellite data as a key component to quantify the status and

major changes in the composition, distribution, structure, and function of Canada's forests. The EOSD will support Canadian priorities and international commitments such as the criteria and indicators of sustainable forest management, Kyoto Protocol commitments, the Convention on Biological Diversity, the Framework Convention on Climate Change, and Global Observations of Forest Cover.

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In addition to remote sensing, the AFT group focuses on the development of new methodologies and techniques for extracting information from remotely sensed data. Data fusion is a critical aspect of the work and involves the use of multisource and multitemporal data for optimizing the extraction and interpretation of information. With over 500 remotely sensed images from the SEIDAM project alone, keeping track of data is a challenge, requiring image metadata to be created and made available to users, as well as the creation of intelligent systems for information extraction. —**Pal Bohgal**, Physical Scientist, Pacific Forestry Centre ▪

Fangliang He

## Spatial structure, competition, and disturbances in coastal Douglas-fir forests

Mortality is a key process in the stand dynamics of trees. Only with mortality and the creation of gaps in the stand can the system move forward through replacement of shade-intolerant species with tolerant ones. I study changes in the space that plant species occupy and changes in species composition. I am currently studying such changes with respect to Douglas-fir.


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Douglas-fir, a colonizer of open areas, starts out by creating dense stands. A sapling is initially under high competitive stress from the other Douglas-firs around it. As the stand matures, some Douglas-firs die because of the competition and gap openings. Shade-tolerant species invade the gaps and gradually Douglas-fir has to compete with different species. As a result, species composition, particularly among understory species, also changes.

Both natural and human activities can disturb ecosystems. If forest management activities are to mimic natural processes, as is generally recommended, we need indicators that tell us how natural and human disturbances are similar and different. For example, we have determined that the long-term effects of silvicultural treatments are localized. We found that the thinning and fertilization of a Douglas-fir stand on southern Vancouver Island did not greatly affect the total number of species in the plantation, but significantly altered the growth and development of some understory species in a way that was not immediately obvious. The growth of understory species is promoted by thinning, but is inhibited by high levels of fertilization. These differing responses suggest we could use understory species as indicators of silvicultural effects on Douglas-fir forests.

Spatial patterning, competition, and disturbances are the fundamental processes of an ecosystem. Understanding the relationship between them is indispensable to understanding the ecosystem. —**Fangliang He**, Plant Ecologist, Pacific Forestry Centre ▪

Blair Helson

## Pest-control products from nature: evaluating alternatives to conventional insecticides

Because conventional chemical insecticides have declined in availability and popularity, innovative approaches to controlling insects capable of causing serious economic damage to forests are needed. CFS scientists are looking at a range of options including genetically engineered viruses, insect-resistant trees, and in my case, natural products. Along with fellow CFS researchers Mamdouh Abou-Zaid, Peter DeGroot, Barry Lyons, Dean Thompson, and Rick West, I identify and evaluate new natural products for managing forest insects in Canada.

We first expose forest insects to the natural product compound in the laboratory. Recently we evaluated an insect control agent called neem. Its active ingredient, azadirachtin, is derived from a tropical evergreen tree called the neem tree. We found that azadirachtin was highly effective, quite comparable to conventional insecticides in its activity. In particular, sawfly, species, such as pine false webworm, introduced pine sawfly, European pine sawfly, and balsam fir sawfly were very susceptible to it. This is of particular interest as few safe alternatives to conventional insecticides exist for sawflies. There are host-specific viruses that can be used against them, but this would involve developing a different virus for each sawfly.

Azadirachtin can be applied systemically; that is, it can be injected into trees. Thus it has great potential for use in urban areas, on cottage properties, and around bodies of water, places where the possibility of drift makes spray application undesirable. It also is useful in situations where only a few hectares are infested by insects, such as in pine plantations and on private woodlots, and where a person would want the option of treating single trees at great risk of dying from the insect attack. We have developed application equipment that can be installed in minutes—drill a hole in the tree, put the device on, and inject.

Trees have natural biochemical mechanisms for resisting insect attack. This is another area of research we are exploring. For example, the forest tent caterpillar will not feed on the leaves of red maple. We think that certain phenolic compounds in the leaves are responsible. They are not present in sugar maple, a species that forest tent caterpillar will feed on. One way to test the antifeedant effects of these phenolic compounds would be to systemically inject red maple leaf extracts into broadleaf species that forest tent caterpillars feed on. We would like to try this approach, starting with laboratory trials and then, if it appears feasible, move to field trials. —**Blair Helson**, Insect Toxicologist, Great Lakes Forestry Centre ▪

Leland Humble

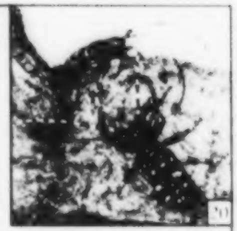
## Detection and quantification of alien insect introductions in Canada

Are there alien insect species in the landscape that have yet to be detected? What can be done to detect alien insects sooner? Our research into alien insects seeks to answer these questions. Without question, the rate at which alien insects are being introduced into Canada is increasing. For example, between 1995

and 1997, the number of known alien ambrosia beetles established in western Canada doubled, from 5 to 10 species. The implications for the health of Canadian forests are as yet unclear, but considering that two native ambrosia beetle species are the dominant cause of wood degradation in west coast forests, there is justifiable concern.

A unique aspect of our research is that it is conducted around a main port, where alien species are most likely to enter the country. In the course of our research, we have encountered subtropical insects as well as temperate insects native to Europe, Asia, and eastern North America. All appear to exist in the Vancouver area. We have sampled dead and dying native trees in forested areas around landfill sites where old wood packaging is disposed and 97%–99% of the individual insects that emerge from a sample are alien. That is a frighteningly large number.

We are now seeking to establish the extent to which these alien species have moved outward, into the forest lands surrounding Vancouver. As a first step, we are setting up an east-to-west sampling study with traps at 30–50-km intervals that will run from the mouth of the Fraser River to Hope, British Columbia. This will help us to estimate the overall proportion of alien to native insects present in the landscape. Similar transects are needed near ports or import centers across the country to determine the extent to which alien species are present in Canada's forest ecosystems and to provide a baseline for measuring whether these populations are increasing either in extent or abundance.



One of the objectives of the research we are carrying out is to provide a baseline for determining the efficacy of regulatory policies aimed at excluding new introductions. Knowledge of the alien species moving in international trade can aid in the development of better detection methods. Such data is also essential for the development of regulations that will reduce the rate of introductions. The Canadian Food Inspection Agency has a clear regulatory role in this matter, but there is definitely a role for the CFS to play. It has not taken a lot of investigation on our part to determine that wood packaging is a main pathway for the entry of potential forest pests into Canada.

Eric Allen and his staff at the Pacific Forestry Centre have started to quantify the risks associated with imported materials such as wire rope spools. A better understanding of the numbers of alien species, and their abundance in import packaging, provides a level of certainty to the Canadian and US regulators who tighten import standards for those materials. For our part, it is a clear example of doing science to support policy, rather than only publishing in a journal. —**Leland Humble**, Entomologist, Pacific Forestry Centre ■

## Impacts of alien plants on the biodiversity of plant communities

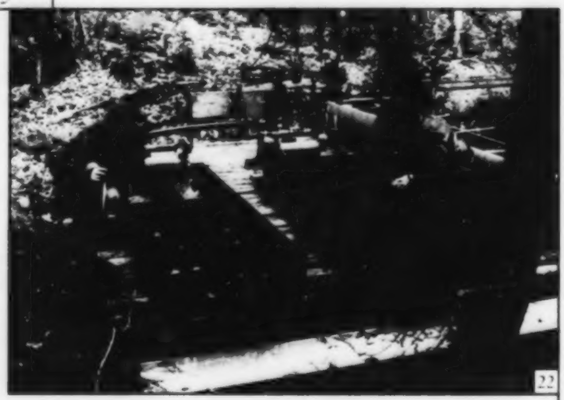
You might say I'm a weed scientist. My most recent project is a study of the impact of alien plants on the native vegetation of British Columbia. Two of the more obvious are gorse and Scotch broom. They were both established in the mid-19th century and are now widely distributed. Both are legumes. Gorse prefers dry sites; Scotch broom can grow just about anywhere. Both plants are highly invasive and have developed extremely efficient mechanisms for colonizing industrial areas, forested areas, hydro-electric right-of-ways—almost anywhere. On cut-over areas they often so completely colonize the

site that few native plants remain. They seriously interfere with the growth of native conifer species such as Douglas-fir and have driven some native grass and butterfly species to the point of extinction. They are also a threat to the very limited Garry oak ecosystem of Vancouver Island. With climate change, their spread may accelerate.

In collaboration with the B.C. Ministry of Forests, the Department of National Defence, Esquimalt, and the Capital Regional District in Victoria, I am trying to determine the extent and nature of competition between these alien plants and native species. Gorse and Scotch broom have spread so quickly partly because there is no control agent for them in nature. We are looking for a natural control and are conducting greenhouse trials of the fungi *Chondrostereum purpureum* (Pers:Fr) Pouzar and *Fusarium tumidum* Sherb. The former is a proven mycoherbicide, which has been tested on other hardwood weeds, and the latter shows great potential to inhibit and control the growth of the two alien species. Much work remains to be done, including finding a native isolate of *F. tumidum*. Because the seeds are the principal mechanism by which these alien plants spread, we will also investigate factors that might affect seed germination. —**Raj Prasad**, Plant physiologist, Pacific Forestry Centre ■

David Kreutzweiser

## Monitoring aquatic organisms as indicators of environmental quality



Aquatic invertebrates are not the typical subjects for forestry research. In fact, they are very good indicators of environmental quality, and the aquatic systems they inhabit are closely tied to surrounding terrestrial environments, including forests. Monitoring the presence and condition of aquatic invertebrates in headwaters is of particular concern. Most headwaters in Canada are forested, which means forest management activities are likely to occur in these areas. If you alter the ecology of a headwater through forest management, it affects a lot of things downstream.

We look for changes to aquatic vertebrate species composition and abundance that may result from changes in the surrounding forest. We are now monitoring several areas at the Black Sturgeon Lake and Turkey Lake forest research sites in central Ontario, where a range of harvesting regimes and partial retention methods are being evaluated. We believe that if a particular harvesting technique alters the type or amount of material entering streams in the area, the change will be reflected in the local invertebrate population.

Aquatic invertebrates are also used to evaluate the effect that specific compounds, such as pesticides used in forestry operations, have on aquatic systems. If the compound to be evaluated does not normally occur in the ecosystem, for example, a genetically engineered baculovirus or a bacteria, tests begin in our laboratory, at the microcosm level. A microcosm is a model that mimics the natural environment. We construct a microcosm and introduce the test compound and a sample population of aquatic organisms. Typically, we monitor respiration activity, feeding rate, growth rate, and survival, all of which indicate whether the compound being tested is likely to cause a problem outside the laboratory. If that does not appear to be the case, the tests are then repeated outside at a more realistic mesocosm scale, more or less to validate our lab results.

Mesocosms are constructed in streams or lakes. For a stream mesocosm, we build a series of channels

adjacent to a natural stream and divert its water through the channels. We then introduce invertebrates for study, or sometimes allow the channels to colonize naturally. We treat some, use others for controls, and look for differences. For a lake mesocosm, we build a floating framework that is divided into squares. Each square has a polyethylene curtain surrounding it that extends from the surface down to the bottom of the lake, enclosing a sample of the natural zooplankton, phytoplankton, and invertebrates present. The entire apparatus functions as a replicated aquatic sample plot.

We believe the information that results from our research is extremely important. Increasingly, it is necessary to clearly demonstrate the safety and sustainability of forest management techniques and materials. That is the sort of information we are in business to provide. —**David Kreutzweiser,** Aquatic Ecotoxicologist, Great Lakes Forestry Centre ■

Mike Weber

## Ecosystem Management by Emulating Natural Disturbance Project

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Ecosystem Management by Emulating Natural Disturbance (EMEND) is the CFS's most extensive fire ecology project. It is a very large scale experiment, covering almost 1 200 ha of northwestern Alberta. There is no ecological study like it in North America.

The purpose of EMEND is to determine to what extent, if at all, cutting patterns used in forest harvesting can be tailored to approximate the recovery from disturbance that occurs after wildfire. In a boreal landscape, it is the mosaic pattern left by fire that creates vegetation diversity. The perimeter of a burned area may enclose a certain number of hectares, but inside that boundary there is always a patchwork of vegetation that remains. That patchiness is incorporated into our experimental treatments: the modified cutting patterns we use will leave small, scattered islands of trees within harvested areas, just as would be expected following a wildfire.

As a fire ecologist, I am excited about EMEND because it is the first large-scale fire ecology experiment that explicitly identifies fire as a control—as the normal condition against which all experimental treatments in the project will be measured. There are 24 experimental burns to be applied over the next 2 years. Because each treatment will be fully replicated, we will be able to statistically evaluate our data and draw conclusions on a scientific basis. EMEND is a multidisciplinary project, and studies of insects, small mammals, and vegetation ecology within the treatment areas will also be conducted. The province of Alberta is an important collaborator in the project. Its assistance is critical because as federal researchers we have no mandate to conduct experimental fires on the ground. That, jurisdictionally, must be done by the province, which has been involved from the beginning.

In addition to taking place over a large spatial scale, the EMEND study will take place over a long temporal scale. The land for the experiment was donated by private forestry companies and they insisted this project be long term. At present, the study is projected to require one forest rotation—the time it takes for a tree to grow from a seed to harvestable age. In northwestern Alberta, that is between 100 and 120 years. We will all be long gone before the experiment ends, of course, but we hope that our comprehensive documentation will allow others to carry on our work. We expect future researchers will ask questions about fire ecology that we never thought of. —**Mike Weber**, Fire Ecologist, Northern Forestry Centre [now Director, Integrated Resource Management Division, Great Lakes Forestry Centre ■


Forestry in Canada is anything but a "sunset" industry. The forest sector continues to contribute substantially to the health and stability of the Canadian economy. In 1998, 877 000 Canadians, fully one in sixteen, earned their living directly or indirectly from the Canadian forest. That same year, forest industries contributed $31.7 billion to the national balance of trade and $18.2 billion to the gross domestic product. The tangible economic benefits derived from having 10% of world forest resources in Canada have contributed to the quality of life of all Canadians and have allowed the forest sector to maintain extremely high standards of environmental quality.

However, the Canadian forest sector does face an increasing number of challenges. New sources of fiber supply from nontraditional competitors, improved production by traditional forest sector competitors, the growing demand for specialized and engineered wood products, the increasing costs of domestic fiber, and a reduced supply of economically accessible timber place pressure on the forest sector and threaten its share of the international market. Continued Canadian forest sector competitiveness on the world stage will require flexibility and an ability to adapt to change in domestic and international markets. At home, this requires intensively managing commercial forests, improving product production processes, and developing value-added products. Internationally, Canada must continue to increase its knowledge base with respect to client demands, product requirements, international standards, and building code requirements.

CFS research helps to maintain the competitive position of Canada's forest industry through direct generation of scientific knowledge that promotes efficient production and increased diversification of forest products. CFS contributes to innovation in forest management, forest product development, and production methodology through partnerships and collaboration with three not-for-profit institutes: Forintek Canada Corp. (solid wood products), FERIC, the Forest Engineering Research Institute of Canada (forest engineering), and Paprican, the Pulp and Paper Research Institute of Canada (pulp and paper). Both Forintek and FERIC receive significant financial contributions from the CFS.

The CFS actively participates in Forintek projects aimed at the development of new value-added products and production processes. These include intensive investigation and identification of sapstain fungi (organisms that discolour wood and negatively affect the value of high-grade forest products); the development of superheated steam vacuum technology for the drying of specialty wood products; investigation of specific wood properties in western Canadian tree species; and initiation of market studies into composite hardwood flooring use. The CFS also contributes to Forintek research that supports international market access. Projects include the development of computer-based predictive trade models for softwood and logs, harmonization of Canadian wood preservation and protection standards, and the creation of computer-based models for the development of fire-resistant wood construction materials. The CFS has also contributed funding to seismic research on wooden-structure strength as part of a series of earthquake simulation tests in Japan.

The CFS and FERIC collaborate on studies focused on improving tree growth, silviculture techniques, harvesting methods, and methods of wood transportation. Research examples include the development of alternative harvesting and silvicultural systems in boreal mixedwood forest stands, the evaluation of thinning and fertilization treatments for reducing the susceptibility

of lodgepole pine to attacks from mountain pine beetle, and the transformation of carbon and nitrogen in coastal forest ecosystems.

CFS research capacity in the field of advanced genetics and biotechnology continues to grow. As pressure on existing forest resources to provide timber and nontimber products increases, provinces and industry are shifting their attention from extensive management of natural forests to intensive management of second-growth forests and plantations. Improved faster-growing trees, derived through conventional tree breeding and genetic-engineering programs, are a key element in the successful transition to plantation forestry. Also critical to the establishment and protection of high-yield plantations will be advanced silvicultural technologies and effective, but environmentally benign, biological pest-control methods.

CFS biotechnology research has already produced high-efficiency genetic-transformation techniques for production of genetically engineered (transgenic) trees with specific desired traits, including enhanced growth rate, stress tolerance, and resistance to insects and disease. At present, more than 4 000 transgenic seedlings are being evaluated under controlled laboratory conditions, permitting careful study of genetic stability before field trials are initiated. Assuring that engineered genes cannot be transferred to the natural environment is critical, and research into methods for inducing reproductive sterility in transgenic trees is ongoing at the CFS and through collaborative agreements with agencies such as BC Research Inc.

CFS research into somatic embryogenesis, an advanced technology that permits rapid, mass propagation of improved and high-quality tree lines, continues to advance. Studies by CFS scientists and collaborative work with researchers at BC Research Inc. have resulted in an expanded list of species to which somatic embryogenesis technology is applicable. A broad range of commercially important conifers including spruces, larches, and pines can now be propagated in this manner. Investigation of improved methods that will allow use of mature tree material in somatic embryogenesis are now under way. CFS research has also established that somatic embryogenesis source material will remain genetically stable under cryogenic preservation. This makes it possible to develop genetically improved varieties of conifers by defrosting and repropagating frozen embryogenic lines (clones) after genetic testing has shown which are the best performers. In addition, new applications for somatic embryogenesis technology in the field of non-timber forest products, such as pharmaceuticals and phytochemicals, are being pursued.

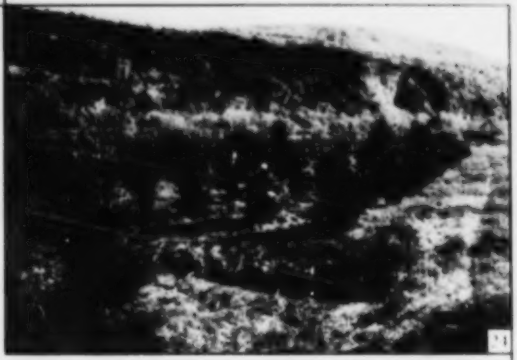
The CFS is also working to identify important genetic indicators associated with the control of mature wood density in black spruce, genetic resistance to white pine weevil in Norway spruce, and specific blister rust markers in white pine. Other studies are investigating the use of morphological features for selecting white spruce seedlings with heightened levels of environmental stress tolerance. CFS researchers, working in collaboration with Laval University in Quebec have investigated variation in frost resistance of black spruce and delineation of geographic zones in which seed can safely be moved and planted. Knowledge derived from studies of this type is contributing to increased plantation production and greater understanding of insect and disease resistance.

Responding to the need for innovative insect pest controls, CFS researchers have collaborated in the identification and genetic engineering of baculoviruses that specifically target spruce budworm. Efficient virus production methods are also being developed. Other research activities include the identification and commercialization of natural pheromones for use in pest control and the use of naturally occurring insect parasitoids, microbial control agents, and naturally occurring antifeedant chemical compounds.

To compete globally requires that Canada make optimum use of its forest resources, from tree seedling to finished product. CFS research is dedicated to developing innovative management and harvesting techniques, faster growth, more stress-tolerant trees, better pest-control technologies, new forest products, and increased understanding of critical market factors, to ensure that Canada is not just a global competitor in the forest sector, but the global leader in sustainable forest management.

Jean Beaulieu

## Tree breeding and advanced genetics



Breeding research is not as straightforward in forestry as it is in agriculture. Crop plants have been the subject of breeding programs for a very long time. Tree breeding programs are rather more recent in comparison and tree populations remain genetically diverse. Nonetheless, much progress has been made. My colleagues at the Laurentian Forestry Centre, Francine Bigras, Gaétan Daoust, and Nathalie Isabel, and I have recently established four different genetic markers directly associated with mature wood density in white spruce. By selecting and breeding trees that carry these markers in their DNA, we estimate we can achieve 5% genetic gains in wood quality. We are now working to identify other markers related to economically important and adaptive traits in spruces, as well as genetic markers that will aid in the general study of conifer genomes.

We are very interested in the effect of tree breeding on biodiversity, including the effect of introduced seed on locally adapted seed complexes. We consider natural populations to be well adapted to local site conditions. Most reforestation projects, however, result in the introduction into an area of seeds and seedlings that originated elsewhere. Inevitably, when this introduced material becomes mature, pollen exchange with trees in the local population results. To determine whether this hybridization results in progeny with reduced adaptation to local conditions, we are crossing trees from our own provenance trials with material collected in local forests.

One of the requirements of a tree breeding program is the development and preservation of genetic resources. We maintain a seed bank that contains more than 10 000 seed lots, collected from all of the species we use in our research, and a pollen bank that contains more than 9 kg of pollen from six different conifer species. We have established over 100 genetic tests throughout southern Quebec, and many of our provenance tests involve material moved from north to south, which simulates to some extent the effect of a warming climate on tree growth. Those tests will be very useful in estimating the effect of global change on local forests. —**Jean Beaulieu**, Research Scientist, Laurentian Forestry Centre ■

Armand Séguin

## Genetically engineering pest-tolerant trees

Genetic engineering is a fast and dependable method of producing a tree with specific, desirable traits. Traditional tree breeding methods require that genes be randomly mixed and as a result, although a trait such as pest resistance might be improved, there is always a risk of simultaneously altering a desirable trait, such as rate of growth. Because genetic engineering focuses on one specific gene and one specific trait, it is a much more precise method of tree improvement. It is also much more expensive, because of the technology, personnel, supplies, and equipment required. However, recent progress in the transformation and development of tools has made the technology much less costly. Based on techniques we have developed

over the last 10 years, even small biotech companies can now consider producing their own transgenic trees.

Genetic engineering is actually based on a very simple principle—the way in which genes function. Our goal is to be able to insert a protein that controls a trait into a tree. *Bacillus thuringiensis* (*B.t.*), for example, widely used as a nonchemical insecticide against Lepidoptera insect larvae, is a protein. In the past, *B.t.* protein, normally found in bacteria, was grown in a laboratory and then sprayed on trees. This type of protein product has been part of the environment for some time. Now we and several genetic engineering laboratories have taken a different approach and are developing trees that will produce *B.t.* directly. It requires isolating the gene that codes for *B.t.* protein and then inserting that gene into the tree species you wish to make resistant. An important collaborator in this effort, Illimar Altosaar of the University of Ottawa, has recently provided a synthetic *B.t.* gene.

We know that insects inevitably develop natural resistence to a single control measure. In genetically engineering resistant trees, we are able to take advantage of a technique known as gene stacking. Gene stacking involves inserting two or more different genes—each with a different mode of action against the target insect—into the plant to be engineered. For our *B.t.* producing trees, we intend to use a wound-inducible promoter gene that will act as a switch, turning on *B.t.* production only if a tree is under physiological stress resulting from insect attack. For a second mode of action, we are considering adding a protease inhibitor gene. Protease inhibitors are small proteins that bind to enzymes produced internally by insects, causing the enzymes to be produced in excessive amounts. The insect does not die as a result but eventually its development slows or stops. By stacking *B.t.* and protease inhibitors, the possibility of the insect developing *B.t.* immunity is reduced exponentially rather than simply by half. —**Armand Séguin**, Research Scientist, Laurentian Forestry Centre ■

## Spruce budworm control with biotechnology

By developing pest specific control agents and reducing the use of broad-spectrum insecticides, we can decrease economic losses caused by forest pests and minimize adverse effects on the environment. The advent of biotechnology has permitted the development of target-specific biopesticides. Our goal in using biotechnology is to understand an insect pest at the molecular level, and use the information to develop better ways of controlling it. We not only understand the biology of the insect at the fundamental level but also are able to identify the vulnerable stages where we can control the pest. Insects have evolved for millions of years and have an arsenal of tricks to thwart many of our control strategies. Therefore, we must develop many control methods, so that if the insect develops resistance to one, we can always use another method.

One control method we have pursued for spruce budworm takes advantage of the fact that the larvae have to periodically shed their exoskeletons. When a larva reaches a critical size, it has to molt to allow further growth. The spruce budworm, for instance, has six larval stages and finally stops feeding and transforms into a pupa from which emerges the adult moth.

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We now know that molting is initiated by the molting hormone inducing the expression of a sequence of genes. These gene products are responsible for all the changes that a larva undergoes during the process of molting and metamorphosis. We have identified several key regulatory genes that control the molting process.

Meanwhile, our virology associates have characterized some baculoviruses that are budworm specific, and developed methods for inserting foreign genes into these viruses. We engineered a molt-regulating gene isolated from the spruce budworm into the spruce budworm virus to make it more virulent. On ingesting this transgenic virus, the larva stops feeding and undergoes an incomplete, precocious molt that is lethal.

Although we have demonstrated the proof of the concept, we still need to fine-tune and optimize the system before we can embark on contained field trials. The nice thing about this system is that we are not introducing anything new to the ecosystem. The gene that we have engineered comes from the spruce budworm. The virus is specific to the spruce budworm and makes the entire control strategy environmentally attractive.

The powerful techniques molecular biology provides will allow us to devise better and more potent control methods that are not only pest specific but also environmentally benign. There are many more systems that are currently being investigated by our team at the Great Lakes Forestry Centre. —**Arthur Retnakaran**, Project Leader, Biotechnology Unit, Great lakes Forestry Centre ▪

## Deriving a forest productivity model from ECOLEAP research

One of the main objectives of the Extended Concertation for Linking Ecophysiology and Forest Productivity (ECOLEAP) project is to assemble the results of individual studies into a spatial model of forest productivity. We thus combine scientific exercise with the provision of information useful for addressing international issues, for assessing Canadian landscape productivity, for defining forest biomass, and for evaluating site potential. All these issues are important to our clients.

Evaluation of forest productivity within Canada still relies on the periodic remeasurement of permanent sample plots. Remeasurement intervals are usually between 5 and 10 years, depending on the program. These measurements are then matched to maps of forest types to produce overall estimates of forest productivity over large territories. Key to this procedure is the concept of site index, which is based on the height of a tree at a given age. It is a classical approach that has its roots in the traditional even-aged, single-species forest management of Europe. It has served forestry well in the past, but emerging forest-related issues require information that appears to be beyond the capabilities of plot-based methodology. A classical, empirical approach cannot identify underlying mechanisms of growth and therefore cannot be used to predict the effect of external events such as insect epidemics or climatic change. There is, as well, a need to assess the error associated with estimates of productivity, which is very difficult to obtain using current methodologies. A tool is required that will reflect these factors and address errors associated with prediction over time.

An additional constraint is the need to produce a tool that forest managers will want to use. Our ultimate goal is a process-based model, one that uses biophysical variables such as temperature, precipitation, absorbed sunlight by the plants, and numerical representation of the topography. The development and implementation of this model will be time-consuming. However, at forest inventory agencies across Canada,

people are working on an operational basis—they have to supply vast amounts of information to clients who make decisions affecting millions of dollars of planning and infrastructure investment. These people already have methodologies in place and will not adapt easily to a radically different methodology. As a first step toward more complex tools, we will produce simple predictive tools that can be incorporated easily into operational procedures. Building these types of tools will help us to develop a more complete procedure and will ease the eventual adoption by forest managers of more complex, biophysically based tools. —**Pierre Yves Bernier**, Research Scientist, Forest Ecophysiology, Laurentian Forestry Centre

Other major contributors to the ECOLEAP project include Frédéric Raulier, Huor Ung, Gilles Robitaille, Mike Lavigne, and Guy Larocque. ■

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# Forest Stewardship: Forest Management Practices

The Canadian forest sector is currently faced with the difficult task of satisfying world demands for dependable and regulated fiber supplies while balancing constraining and often conflicting imperatives to protect the environment, to make silvicultural decisions that are socially and economically rational, and to maintain a forest landscape that accommodates recreational and nontimber forest uses. To fulfil these expectations and manage Canada's forests sustainably, forest managers and forestry workers urgently require technical information and decision-support tools that are relevant to their immediate needs, operate effectively, and are sufficiently flexible to allow continual adaptation and improvement.

Research is steadily increasing the sum total of what is known with respect to forest science, and experience gained on-the-job is providing insight into ways of practising forestry more efficiently. To encourage communication of newly available knowledge and technologies on the one hand and newly discovered knowledge gaps and management needs on the other, effective links between researchers and forestry personnel need to be maintained and enhanced. Accelerated transformation of scientific data into technical guidelines and manuals that meet the needs of forestry practitioners is required, as is an increase in opportunities to exchange insights gained through first-hand experience. To make better use of information as it becomes available, information technologies and predictive models that can integrate biological and operational knowledge are needed. Perhaps most critical of all, forest managers require viable, operationally proven, alternatives in choosing forest-harvesting methods.

A stated purpose of the CFS S&T program is to provide forest stakeholders with the tools and information they require to perfect sustainable forest management. By specifically directing research towards forest ecosystem processes, effects of forest practices, forest health, forest biodiversity, forest pests, wildfire research and climate change, the CFS generates relevant scientific data and translates it into technologies, forecasting methods, and predictive models that directly support decision-making by forest managers. Technology transfer, commercialization, and development of cost effective forest practices are all integral parts of the CFS mandate.

CFS researchers contribute posters and papers to conferences and workshops, conduct field trips and technology transfer tours to research sites, and regularly publish research results in peer-reviewed scientific journals, including the *Canadian Journal of Forest Research* and the *Canadian Journal of Botany*. To ensure Canadians remain informed about critical forestry issues that influence the future direction of its science program, the CFS has produced a series of context papers that address topics such as forest health, alien forest pests, and the implications of climate change. Discussion papers examining management applications of genetically engineered baculoviruses and multiyear strategic plans covering forest biodiversity and bioenergy research have also been released.

To provide information and technology transfer in the area of biodiversity, the CFS has established the National Forest Genetic Resources Centre and the National Tree Seed Centre at the Atlantic Forestry Centre in Fredericton. This facility will assist in the preservation of forest genetic diversity and make tree seed available to regional, national, and international researchers. CFS researchers are currently cataloguing key forest taxa, including plants and arthropods, from representative forests across Canada. They are developing methods for identifying ectomycorrhizae, fungi whose presence and function in forest soils are directly linked to forest

productivity. To determine the origin of the introduced fungal pathogens, including scleroderris canker disease, CFS scientists are comparing canker samples from Ontario with samples collected from sites in Europe. Studies to perfect simple, user-friendly detection methods for white pine blister rust in commercial nursery stock are ongoing, as are efforts to identify mechanisms by which the fungus spreads. Instant online access to a searchable British Columbia host–fungus index and herbarium database and to a forest insect and disease diagnosis system is provided by the CFS Pacific Forestry Centre Web site at http://www.pfc.cfs.nrcan.gc.ca/main/index.html.

A spruce budworm decision-support system developed by the CFS is directly assisting forest managers in the Maritime provinces and Quebec to make planning and harvest decisions that minimize spruce budworm damage. CFS researchers have also developed techniques for manipulating forest stands in ways that minimize pest infestation and the need for pest control interventions. These techniques are currently being assessed and refined. CFS researchers, in collaboration with the Quebec Department of Natural Resources, Laval University, Québec, and Carleton University, Ottawa, have begun research work aimed at applying current knowledge of spruce budworm population dynamics to develop strategies for early intervention, based on how insect outbreaks develop and expand. As well, by analyzing historical spruce budworm defoliation patterns, CFS researchers have created a defoliation forecasting tool for use in the next spruce budworm outbreak in the province of Quebec.

The temporal, spacial, and behavioral patterns of forest pests are also being studied. CFS researchers in Quebec have developed BIOSIM, a software tool that employs simulation models to forecast critical events in the seasonal biology of insect pests. Because the software can be modified to accommodate differing air temperature and precipitation values, it is readily transferable to other forest regions. Currently, BIOSIM is being used in a gypsy moth eradication program in British Columbia. CFS research continues on the discovery, patenting, and commercial registration of insect pheromones that can be used to monitor and control native and alien pests. Natural product insecticides, such as azadirachtin, are currently being tested to establish their environmental safety, efficacy, and cost-effectiveness for use in forest management.

CFS research has furnished forest managers with a stand-density management tool for black spruce that provides an objective method for determining initial spacing and thinning densities in order to achieve timber, vegetation, and wildlife management objectives. The tool is currently being adapted to accommodate other commercial tree species. CFS scientists are collaborating on long-term research in Alberta to test innovative harvesting methods that permit removal of an advanced aspen crop while retaining and minimizing damage to advanced white spruce regeneration on the same site. Results after 5 years suggest forest managers can protect 50% to 60% of the residual spruce and at the same time produce significant diameter and volume increases in the retained crop trees. The silvicultural methods demonstrated are already being adopted and modified by forest-harvesting companies. CFS scientists are also contributing to the Black Sturgeon Boreal Mixedwood Project, a collaborative project in Ontario's second-growth spruce, fir, and aspen mixed forests. Harvesting impacts on residual trees, postdisturbance vegetation succession, and the application of alternative harvesting and silvicultural practices are major components of this study.

To provide critically needed operational information to forest managers, CFS scientists, working together with a client advisory committee, have initiated a major report on the costs and benefits of partial cutting as an alternative to clearcutting. The report, based entirely on scientific findings, will represent a tangible and positive contribution to future discussions of clearcutting alternatives. Already, CFS research carried out as part of the Montane Alternative Silvicultural Systems (MASS) cooperative study has directly influenced MacMillan Bloedel Limited (now Weyerhaeuser Company Limited) in phasing out clearcutting in British Columbia coastal forests. Research results of the study have lead to major changes to management practices in montane forests. As well, findings from the Coastal Forest Chronosequence Project, a CFS collaborative study comparing stages of forest development from regeneration to old growth, are being used to guide alternative, nonclearcut harvesting plans on private lands.

The CFS has been and will continue to be the national leader in developing specific tools and techniques, predictive models, and management guidelines that will allow forestry personnel to increase the efficiency of management practices while protecting the

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environment and maximizing social and economic opportunities. Perfecting alternative approaches to forest harvesting and developing know-how in the intensive management of second-growth forests and plantations are the next stewardship challenges. The CFS is already working to provide the information needed to meet these challenges and to achieve the greater goal of practising fully sustainable forest management.

## Identifying factors affecting aspen regeneration in northern Alberta

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environment and maximizing social and economic opportunities. Perfecting alternative approaches to forest harvesting and developing know-how in the intensive management of second-growth forests and plantations are the next stewardship challenges. The CFS is already working to provide the information needed to meet these challenges and to achieve the greater goal of practising fully sustainable forest management.

Ivor Edwards

## Identifying factors affecting aspen regeneration in northern Alberta

**In the mid-1980s, technologies to use aspen for pulp and paper products were developed, and the government of Alberta issued permits to companies to undertake the harvesting of aspen stands. Aspen regenerates mainly vegetatively. After a tree is cut, new shoots, called suckers, sprout from the roots and develop into a new tree. This attractive feature of aspen was readily apparent—postharvest regeneration costs would be nonexistent. However, provincial authorities discovered that aspen was not regenerating well along skid trails on harvested sites, and in the early 1990s, the CFS silviculture group was asked to investigate the problem. As my background is soil chemistry, I was given the task of looking specifically at soil conditions on the harvested sites.**

**In 1994, we started studying aspen harvesting at Manning, Alberta, 700 km northwest of Edmonton. Although heavy feller-bunchers and skidders were being used in the harvesting operations, these machines did not seem to be damaging the aspen roots. The problem, I deduced, involved soil compaction. Harvesting under moist summer conditions takes a toll on critical soil qualities such as porosity and bulk density, especially in finely textured soils that are inherently low in large pore space. Suckering is a temperature-driven phenomenon: for soil temperature to increase to a level that will support optimum suckering, a certain amount of air-filled pores have to be present. A wet soil remains cool and does not promote suckering. Anything that compromises soil temperature, such as excessive moisture and low porosity, will be constraining to regeneration.**

**A partial solution to the problem may be to harvest in the winter when the soil is frozen and the resulting compaction and decrease in porosity are negligible. One drawback is that for some forestry companies, the unit costs of harvesting are higher in winter than they are in summer. But for optimum regeneration of aspen, unless it is possible to harvest finely textured sites under dry conditions in late summer and fall, winter seems to be the best season in which to harvest. —Ivor Edwards, Research Scientist, Northern Forestry Centre ■**

## Seedling stress tolerance under postharvest partial canopy retention

As part of a project to test alternatives to clearcutting, I am comparing the effects of different levels of canopy retention after harvesting on natural and planted regeneration. What this really means is identifying how different levels of shade affect tree regeneration. When people look at different canopy treatments, they see variety in the light conditions. The question I want to answer is whether plants see that variation as well. To do so, I am measuring foliar nitrogen, chlorophyll, water retention, photosynthesis—the physiology of regeneration. Much of my work takes place at the Montane Alternative Silvicultural Systems (MASS) research site near Campbell River on Vancouver Island, British Columbia. It is a multi-agency partnership led by the CFS and MacMillan Bloedel Limited (now Weyerhaeuser Company Limited) that includes the Forest Engineering and Research Institute of Canada (FERIC), the B.C. Ministry of Forests, the University of Victoria, and the University of British Columbia.

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Our research shows that from a trees' point of view, there may not be a great difference in any of the silvicultural systems being studied. Presumably, shade-tolerant tree species should be the best choice to use in this kind of environment, where there is some sort of tree canopy being retained overhead. What we found, however, is that the trees do not really seem to care much about shade; apparently, they are incredibly tolerant of an extremely wide range of conditions. We subjected seedlings to artificially manipulated levels of shade and nutrition and have found that it takes about 60% shade to cause a significant reduction in seedling biomass. Trees acclimatize when the degree of environmental change becomes sufficiently large. I now want to find the thresholds for this response. I also hope to identify the physiological basis of stress tolerance and establish whether it is a constant characteristic or one that changes. —**Alan Mitchell**, Tree Physiologist, Pacific Forestry Centre ▪

## Biologically based decision-support tool for stand density

The way trees compete for space affects the quantity and quality of their wood. Plant growth analysis has long been used in crop research. Agriculturists found that by changing a plant's environment through density control, they could then direct resources to developing the most economically desirable component of the plant. In corn, it would be the ears. In trees it is usually the stem size.

Researchers are now applying plant growth analysis to trees. We have identified ways in which the various parts of particular tree species are affected by density stress, and conversely, when competition is reduced, the parts that respond to the extra space given the tree. Using the results from these studies I have designed a stand-density decision-support tool. The computer program creates multiple simulations of tree growth under various combinations of site quality, tree spacing, and other operations criteria. It helps forest managers decide how closely together trees should be growing to minimize the time it takes to produce a merchantable crop.

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This stand density decision-support tool has been successful partly because it is based on ecological and biological concepts. The relationships that underlie the program are not just empirical equations; they also include a component of the natural self-thinning and yield relationships that we know govern growth and competition in plant communities. The model the program contains was specifically designed to simulate black spruce growth, but in collaboration with researchers in Ontario and British Columbia, I am adapting it to a range of tree species. I have also extended the model to describe carbon dynamics so that the implications of various density regimes on net carbon budgets can be determined.

As a next step, I want to adapt this program to simulate the entire array of managed conditions currently being implemented throughout Canada, ranging from natural stand management and partial retention systems all the way to fully managed plantations. Many forest managers are moving from natural to managed stands through precommercial thinning and partial retention systems; we therefore need to incorporate those types of management regimes into the program. —**Peter Newton**, Biomathematician and Forester, Great Lakes Forestry Centre ▪

## Modeling the spatial dynamics of spruce budworm epidemics in Quebec

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The last epidemic of eastern spruce budworm in Quebec took place from about 1965 to 1994. During that time an estimated volume of timber equivalent to 10 years' worth of harvest was lost. Another epidemic may be starting in western Quebec, in the Ottawa River Valley. We would like to determine where and when the epidemic will occur and be able to provide an estimate of its severity. I have been working with Jacques Régnière, a fellow researcher at the Laurentian Forestry Centre, and Bruno Boulet of the Quebec Ministry of Natural Resources to develop a predictive model for budworm epidemics.

Our approach has been to look for patterns in the last epidemic; we are assuming that elements of a spruce budworm epidemic are going to be repeated. We have an excellent data set provided by the Quebec Ministry of Natural Resources—yearly records of defoliation in every location across the province. The Ministry has divided the province into about 9 500 cells. We assigned 30 characteristics to each of these cells—one characteristic for each of the years from 1965 to 1994—and a numerical value to each characteristic. For example, if there was no defoliation in a year, the value of the characteristic was zero. If the defoliation was moderate in a year, the value of the characteristic was one. When we grouped together cells with the greatest similarity, we ended up with 25 different types of outbreaks during the 1965–1994 epidemic. We have used the information to design a model to predict budworm activity over the next 30 years.

What does our model tell us about the next spruce budworm epidemic? It suggests the next outbreak will begin across the province in a west-to-east pattern, earlier in the west, later in the east. Outbreaks that occur in a given area are likely to have a specific duration, from 3 to 12 years.

How accurate is our model? It may not be exact, but already some of its predictions are being realized.

General trends of the previous epidemic are being repeated, as predicted by the model. Our model says that the earliest signs of another outbreak should have been evident in the Ottawa Valley a few years ago and in fact they were. Our model says that we should see the start of an outbreak in the Maurice River Valley, and we have.

The model as it exists now is purely empirical. Our next step is to determine what scientific evidence we have that the epidemic will be repeated. —**David Gray**, Entomologist, Laurentian Forestry Centre ■

Richard Hamelin

## Developing a user-friendly fungal pathogen diagnostic kit


Identifying fungal pathogens and tracking their movements is extremely difficult, chiefly because the damage they cause does not appear until many years after a tree has been infected. Seedlings often look healthy while they are growing in nurseries, but only because conditions are not optimum for a disease to develop fully. In 1978, the European race of the fungus *Gremmeniella abietina,* which causes a serious canker disease in pine species, was detected in Canada for the very first time. Not long thereafter, scleroderris canker, as it is called, had spread almost everywhere in Canada that red pine seedlings are grown. We know that most fungi can move only a few metres per year unassisted and therefore it is likely that the nursery distribution system spreads the fungus.

Identification of fungal strains is equally problematic. There are actually two races of scleroderris canker in Canada—one native, the other alien. The North American race can seriously affect seedlings, but larger trees generally have only their lower branches attacked—trees can grow out of it. The European race, however, kills mature trees outright. Furthermore, there are three races of scleroderris in Europe, one of which is severely affecting lodgepole pine, a tree species introduced there from western Canada. We don't yet have that particular race of scleroderris in Canada, but if it is introduced it could devastate western pine stands. It is very important to know exactly what pathogen you are dealing with. Although these fungi differ in virulence and host range, they cannot be differentiated by visual inspection. You have to use DNA to correctly identify each race.

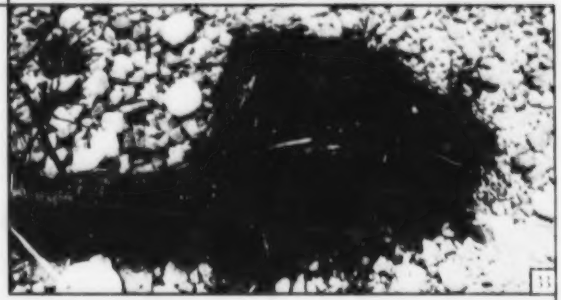
In association with Gaston Laflamme, I have developed a DNA identification technique for fungal pathogens, somewhat similar to techniques used in medical science to diagnose cancer. Our technique is extremely reliable and can detect a single infected seedling in a seedlot of 1000 healthy ones. The technique is fast because we do not need to culture the fungi—hundreds of samples can be processed within a day, compared with several weeks with conventional techniques. It is also nondestructive, because we can work with tiny amounts of DNA collected from conifer needle tips.

At present we are attempting to develop a user-friendly disease detection kit that would function like a pregnancy test—something that would yield a color reaction in the presence of infection. We are still far from doing so, but the technology required is developing rapidly. One of the newest technologies available, called Biochips, combines a computer chip with DNA probes, allowing several thousand probes to be tested simultaneously. The cost of development means this technology is currently not affordable for forest pathogen work alone, but we are discussing the possibility of combining our efforts with those of other scientists in the fields of agriculture and medicine. It is only a matter of time before we can apply this sort of high-tech approach to forestry-related problems. —**Richard Hamelin**, Research scientist, Laurentian Forestry Centre ■

Rona Sturrock

## Laminated root rot: host–pathogen interactions and host resistance

Laminated root rot, caused by the pathogenic fungus *Phellinus weirii* (Murrill) R.L. Gilbertson, not only kills trees but reduces growth and forest productivity. The fungus occurs in British Columbia and the western United States, and unlike many other disease fungi, was not introduced to North America. It probably evolved with Douglas-fir, which is the major species it affects.



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In the past, the focus of root rot research was basic biology—defining host susceptibility, developing management techniques, and modeling how the fungus and disease work. It involved root excavation, mortality surveillance, and sample-plot establishment. Essentially, we were trying to determine what would happen when certain techniques were applied. Increasingly, however, we are looking at the biology of infection, that is, how the disease gets into roots and what it does to trees physiologically. My research now focuses on host–pathogen interactions and host resistance. I study the biochemical response of trees to infection and try to determine the molecular nature of responses. I am also soliciting the knowledge and expertise of other researchers such as protein chemists and geneticists and using tools such as protein chemistry, histology, gene identification, and gene sequencing.

We still look at management techniques, in particular those more closely aligned with alternative silvicultural systems, because this is the industry focus. I work in collaboration with the B.C. Ministry of Forests, Timber West, and MacMillan Bloedel Limited (now Weyerhaeuser Company Limited), and my research is supported in part by Forest Renewal BC. We hope to provide information and fine tune some of the silvicultural response models that have been created. We also still excavate tree roots in the course of our research. Although this is difficult and cumbersome, it remains the best way to do these types of studies. —**Rona Sturrock,** Forestry Research Officer, Pacific Forestry Centre ▪

Les Safranyik

## Suppressing bark beetles with forest management methods

Bark beetles are the most destructive pests in the forests of British Columbia. In 1984 the mountain pine beetle, one of five highly injurious species in British Columbia, killed over 50 million trees, representing an area of more than half million hectares. Bark beetles cause mortality by penetrating under the bark of susceptible trees; they carry with them symbiotic fungi that are highly pathogenic to tree cells. Successfully attacked trees are invariably killed, most within 3 weeks to a month.

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Research on the characteristics of the interaction between bark beetles, their associated symbiotic fungi, host trees, and stands has indicated that it is possible to manipulate forest conditions to suppress beetle establishment and survival. In cooperation with the B.C. Ministry of Forests, and the forest industry, we are evaluating the effect that spacing and fertilizing lodgepole pine stands in southeastern British Columbia has on suppressing mountain pine beetles. Our approach is to thin stands to a known

spacing and then assess infestation of the residual trees on a yearly basis.

One of the objectives of this study is to give a more definitive answer as to why stand thinning has this effect on bark beetles. Previous research suggests that emerged adult mountain pine beetles are quite sensitive to light, temperature, and wind movement. Increased light and heat on the lower boles of trees following spacing tend to stimulate flight and dispersal out of the stand. As well, to find susceptible trees, bark beetles follow wind-borne pheromone plumes released by beetles that have already attacked a tree and penetrated under its bark. Increasing the space between trees means more sunlight reaches the ground, creating thermals that may break up these pheromone plumes. Also, these beetles are relatively poor flyers. Opening up a stand increases wind velocity to a point that it becomes physically impossible for them to follow a pheromone plume to its source. An added factor is the increased growth that often occurs following spacing and fertilization. It increases resin production, a trees' primary means of defence against bark beetles.

We also investigated how controlled burns in infested lodgepole pine forest stands affect the spread of mountain pine beetle infestations. Our data are limited, but we have observed approximately 50% mortality of mountain pine beetle brood following one prescribed fire. This is not enough to cause a decline in the infestation, but almost certainly enough to slow its spread. Prescribed fire is a potential tool that could be particularly useful in parks and nature reserves, where the use of chemical and other direct methods of control is often restricted.—**Les Safranyik**, Research Scientist, Pacific Forestry Centre ▪

## Building a mountain pine beetle infestation and impact model

A model that explores interactions between mountain pine beetles, host trees, parasites, and predators was developed by CFS research scientist Les Safranyik and Hugh Barclay. We have taken that model and adapted it to make a tool for forest managers that predicts tree losses from mountain pine beetle infestation. They can also compare various stand treatments and project a range of outcomes that might result from a beetle infestation. Because we are dealing with biological systems, it is difficult to make predictions that are absolutely accurate. Our aim is to be able to predict which of a range of treatments might be best for saving the greatest number of trees over a period of time.

To operate the model, different types of data inputs are required, including information about the beetles and the age and species composition of the forest area or stand. As an option, management-decision information, such as modifications to the stand or changes to the spacing between trees, can also be included. The impact that treatments such as chemical application will have on the beetle population can also be simulated. However, as the model is intended to be a tool for forest managers, we are primarily concerned with predicting the impact beetles will have on the forest area or stand.

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The ability to predict the timing of insect outbreaks is extremely valuable in forest management. Depending on the conditions operating at the time an outbreak begins, damage to the forest from bark beetles may be not be noticed for several years or it may be immediately apparent. We want to provide models that can predict how an outbreak will behave so that a forest manager can design an appropriate strategy for dealing with it. —**Bill Riel**, Research Officer, Bark Beetle Decision Support Systems, Pacific Forestry Centre ▪

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Almost 80% of Aboriginal communities in Canada are located in commercially productive forest regions. As the process of land claim settlement and treaty negotiation continues, First Nations have the potential to emerge as stewards of a significant forest land base. Aboriginal peoples and communities need to become directly involved in forest management if they are to benefit fully from the opportunities the resource offers for increasing economic development, employment, and revenue generation. Greater technical and operational capacities to practice long-term, sustainable forest management need to be developed. An Aboriginal research agenda focused on technology transfer, forest product innovation, and the distinctive needs of First Nations communities could form the basis of such an undertaking. Increased community access to current scientific knowledge, delivered through workshops, partnerships, publications, and electronic media such as the Internet, could also greatly contribute to development of forest management skills and knowhow in First Nations communities.

At the same time, increased recognition must be given to the considerable body of traditional ecological knowledge possessed by First Nations peoples. Forests have for thousands of years played a central role in many Aboriginal cultures, resulting in a unique ecological perspective and a body of knowledge that could directly contribute to Canada's goal of sustainable forest management. Certainly differences in perspective as to the way knowledge is generated, recorded, and communicated exist, and these differences add to the difficulty of integrating traditional Aboriginal knowledge into forest research and management practices. The custodial rights of First Nations to this knowledge and to the way in which it is recorded and communicated must be fully maintained and respected. However, greater appreciation of the validity and application of traditional knowledge in forest management is timely and appropriate.

Ultimately, sustainable forest development is a goal shared by all. By developing new relationships, capacities, educational exchanges, and mutual understanding, opportunities are enhanced for all to benefit from the forest resources of Canada.

The CFS is working with the National Aboriginal Forestry Association and other Aboriginal stakeholders to develop an aboriginal research agenda that will recognize and reflect the needs, values and specific community needs of First Nations peoples. The CFS recognized that achieving the goal of sustainable forest management represents common ground for all and that a successful strategy must integrate traditional and current scientific knowledge while respecting the cultural values and intellectual property rights of First Nations peoples. Acknowledgment of the cultural differences that exist between First Nations and accommodation of differing decision processes and time scales are also required.

The CFS is currently developing workshops and seminar programs with the purpose of increasing the flow of scientific knowledge between Aboriginal stakeholders, academics, and researchers. Investigative studies of the relationship between traditional ecological knowledge and resource management have been undertaken using modern artificial intelligence approaches and techniques. The objective of these studies is to develop methodologies for recording and representing traditional Aboriginal knowledge, which often is communicated anecdotally rather than directly, into digitized, computer-based forms. Socioeconomic studies and stakeholder surveys intended to improve Aboriginal community access to scientific knowledge and economic information through the Internet have also been initiated.

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Forestry-related activities that combine scientific research techniques with documentation and development of Aboriginal traditional knowledge already exist within the First Nation Forestry Program, often including industry and academic partnerships formed within the Model Forest Program. Examples include an ethnobotany and fire ecology study under the jurisdiction of the Ktunaxa Kinbasket Tribal Council (southeastern British Columbia), a project to locate and inventory sacred sites, culturally modified trees, and medicinal plants by the Tla-o-qui-aht First Nation (Tofino, B.C.), and the development of a GIS-based traditional land use and occupancy database by the Liidlii Kue First Nation (Fort Simpson, N.W.T.). As well, the Eel Ground First Nation and the Fundy Model Forest in New Brunswick are collaborating on a study to combine traditional knowledge with the scientific principles of ecology, botany, and plant taxonomy in order to preserve plant biodiversity within Eel Ground Forestry Management Lands. Research into the artificial propagation and regeneration of black ash, a traditional material used in basket-making, has been undertaken by the Confederacy of Mainland Micmacs, in partnership with the Fundy Model Forest and Nova Forest Alliance, in order to develop cultural and economic initiatives. The project is also intended to encourage reestablishment of the precolonization mix of shade-tolerant species that once occurred in the area's forests.

For the CFS, development of an Aboriginal research strategy and methodologies that will improve access of First Nations to scientific knowledge and technology are new initiatives and research efforts are just beginning. What is clear is that many opportunities exist to forge new relationships and to work together, using forest knowledge of all sorts, to achieve the goal of equitable and sustainable forest management.

## Traditional knowledge studies and World Wide Web information systems

**My background is in ecology, but for the last several years I have been working on a systems approach to delivering ecological knowledge and decision support. A systems approach evaluates the interaction between the physical, biological, economic, and social determinants of an ecological system and determines how this interaction affects decision making. For the last 8 years I have been working in particular on artificial intelligence and knowledge-based systems.**

**Because of my interest in different forms of knowledge, I began looking at methods of representing differing values in decision support systems. This led to an evaluation of ways to handle differing codes of environmental ethics. I have been working on forest land management systems, stakeholder modeling (quantifying their values and preferences), and developing the technology and knowledge bases required for working with nontraditional science organizations and information sources. I already have several products built for delivering forest health information and diagnostic systems that were initially produced as disks and CDs, but we are now moving some of these onto the World Wide Web.**

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**A few years ago I decided a useful approach would be to work with First Nations, because they have a very different set of environmental values. Additionally, the CFS has a mandate in this area, unlike many other forest issues that are a provincial responsibility. I designed a project with Holly Meuse, an aboriginal student who had a background in sociology and some experience in silviculture, on the elicitation, representation, and use of traditional ecological knowledge for landscape management. The project was a collaborative one with the Nicola Valley Institute of Technology and the Nicola Tribal Association, located**

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## Traditional knowledge studies and World Wide Web information systems

in the central interior region of British Columbia. We developed a set of questions that related to forestry issues, the use of land, and how different kinds of landscape changes were affecting people's lives. We conducted interviews in the Coldwater, Upper Nicola, Lower Nicola, Nooaitch, and Shackan First Nation communities; we then had the interviews transcribed and subsequently placed in a database on the World Wide Web.

We were trying to illustrate the flow of knowledge—the reasons we had asked a particular question, the range of responses people gave, the set of inferences that could be drawn, and then the links to particular aspects of things like the forest practice code and other land management processes.

The database permits people to see how their information was tracked through the system into final use. It also works in the opposite direction—if you are looking at a particular section of the forest practices code, you can find out what sort of comments were made on a particular issue.

For example, in forest harvesting, concern about the visual quality of the landscape is normally focused on areas along roads. People driving by do not want to see cut areas. But the kind of landscape you would generate if you were taking a First Nations' perspective is quite different. In that context, people do not like to see clearcuts when they are engaged in traditional gathering and hunting, because a clearcut interferes with the spiritual aspect of traditional activities. From a First Nations' perspective, you would be concerned with the landscape in those areas, not along roads. An implication of that is there could be a public perception problem in areas where you have timber management carried out by First Nations. If the broader public sees clearcuts in different places than they are accustomed to, it may create a perception of mismanagement.

The CFS is also interested in ways to best deliver knowledge to First Nation communities. I am researching systems that will deliver a customized knowledge package to a specific community. It would involve development of software that allows a user to access publicly available databases and extract specific information. For example, the program could be used to contact a Statistics Canada's database, input a community's name, and extract all the statistics contained therein. The information could then be used to search other databases. Ultimately, the information would be compiled and assembled on a Web page for the people of the community for which the search had originally been initiated. —**Alan J. Thomson**, Senior Research Scientist, Pacific Forestry Centre ■

The forest science challenges that Canada faces have grown in scope and significance. CFS research has responded. Its science projects have increased in spatial scale from localized forest plots to broad landscape areas and in experimental approach from individual researcher to multidisciplinary teams collaborating with industry, governments, and academia.

Understanding forest ecosystems and developing strategies for advancing sustainable forest management remain priority areas of the CFS S&T program, but all areas of forest research have become intimately linked to broader global concerns—climate change and carbon sequestration, fossil fuel consumption, and the effect of wildfire on carbon budgets. The CFS will continue to provide national focus in the critical area of climate change by tracking its impact on forests and forest ecosystems. Studies of forest responses to atmospheric chemistry alteration and possible alteration of below-ground forest components such as roots and microbial populations have begun. Web-based systems for visualizing global change scenarios are currently under development, and research projecting the effect of climate change on natural disturbance regimes, including forest diseases and insects, is ongoing.

CFS research will continue to assist Canada's forest managers, through development of alternative harvesting methods in primary forests, provision of new technologies and decision-support tools for intensive management of second-growth forests, and increased silvicultural knowledge for practicing plantation forestry. The CFS will continue to develop improved and genetically enhanced trees that will grow faster, produce higher quality wood, and possess greater insect resistance. CFS researchers are working with private and public forest managers to develop land management strategies that will reduce the negative impacts of unwanted fires and maintain the benefits to ecosystem health and biodiversity that fire provides. CFS fire management research and its technology-transfer products will thus be increasingly integrated with forest ecosystem management.

Remote monitoring of Canada's forest resources to fulfil international commitments and national reporting of information needed by the forest community will remain a CFS priority. CFS will continue as a major partner in the Surface Environment Component of the Earth and Environment Program of Canada's Space Plan, through contributions to projects such as Earth Observation for Sustainable Development of Forest. Research to provide a scientific foundation for forest biodiversity policies will continue, including the development of indicators of soil conservation and identification of plant and animal species to measure environmental change. The CFS will develop strategies for protecting plant and animal species at risk in forests and will pursue proactive approaches to monitoring, detecting, and managing alien pests. Databases and Web-based information sources to facilitate identification of pest species in Canada's natural and urban forests are currently under development.

Future CFS socioeconomic research will include the study of possible social and economic effects resulting from forest response to climate change and the exploration of issues relating to community dependence and stability. Studies on the economic effects of biotechnology in the forest sector, value-added forest product opportunities, the expanding role of First Nations in forest management, and the importance of small-scale private lands forestry will also be undertaken.

Now more than ever before, CFS research will be closely integrated with Canadian national and international policy priorities. The CFS has clearly outlined its strategic directions for the immediate future in its strategic plan "Beyond the Millennium 1998–200." The CFS will continue to adapt and change to meet the challenge of sustaining Canada's forests while meeting the demands of an expanding world market. The tradition of excellence in scientific research established by the CFS will continue into the 21st century and by focusing on science and technology priorities for the forest sector will directly support Canadian leadership in forestry worldwide.

# Annex: Scientific Names of Organisms in the Text

**annosus root and butt rot** (disease), *Heterobasidion annosum* (Fr.:Fr.) Bref. (agent)

**Asian long-horned beetle**, *Anoplophora glabripennis* (Mots.)

**aspens**, *Populus* spp.

**balsam fir**, *Abies balsamea* L.

**balsam fir sawfly**, *Neodiprion abietis* (Harr.)

**black ash**, *Fraxinus nigra*

**black spruce**, *Picea mariana* (Mill.) BSP

**bluejoint grass or marsh reed grass**, *Calamagrostis canadensis* (Michx.) Beauv.

**butternut**, *Juglans cinerea* L.

**butternut canker** (disease), *Sirococcus clavignenti-juglandacearum* Nair, Kostichka & Kuntz (agent)

**Canada yew**, *Taxus canadensis* Marsh.

**chestnut blight** (disease), *Cryphonectria parasitica* (Murr.) Barr (agent)

**Douglas-fir**, *Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*

**Douglas-fir beetle**, *Dendroctonus pseudotsugae* Hopk.

**Dutch elm disease**, *Ophiostoma ulmi* (Buisman) Nannf. (agent)

**dwarf mistletoes**, *Arceuthobium* spp.

**eastern white pine**, *Pinus strobus* L.

**European pine sawfly**, *Neodiprion sertifer* (Geoff.)

**forest tent caterpillar**, *Malacosoma disstria* Hbn.

**Formosa termite**, *Coptotermes formosanus* Shiraki

**Garry oak**, *Quercus garryana* Dougl.

**gorse**, *Ulex europaeus* L.

**grizzly bear**, *Ursus arctos* L.

**gypsy moth**, *Lymantria dispar* (L.)

**introduced pine sawfly**, *Diprion similis* (Htg.)

**jack pine**, *Pinus banksiana* Lamb.

**jack pine budworm**, *Choristoneura pinus pinus* Free.

**larches**, *Larix* spp.

**lodgepole pine**, *Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.

**marten**, *Martes americana* (Turton)

**mountain pine beetle**, *Dendroctonus ponderosae* Hopk.

**neem tree**, *Azadirachta indica* A. Juss.

**Norway spruce**, *Picea abies* (L.) Karst.

**pine shoot beetle**, *Tomicus piniperda* (L.)

**pine false webworm**, *Acantholyda erythrocephala* (L.)

**pines**, *Pinus* spp.

**red crossbill**, *Loxia curvirostra* L.

**red maple**, *Acer rubrum* L.

**red mulberry**, *Morus rubra* L.

**red pine**, *Pinus resinosa* Ait.

**red spruce**, *Picea rubens* Sarg.

**sapstain fung**, usually *Ophiostoma* spp.

**scleroderris canker** (disease), *Gremmeniella abietina* (Lagerb.) Morelet (agent)

**Scotch broom**, *Cytisus scoparius* L. (Link)

**silver-haired bat**, *Lasionycteris noctivagans* (LeConte)

**silver maple**, *Acer saccharinum* L.

**spruce beetle**, *Dendroctonus rufipennis* Kirby)

**spruce budworm**, *Choristoneura fumiferana* (Clem.)

**spruces**, *Picea* spp.

**sugar maple**, *Acer saccharum* Marsh.

**trembling aspen**, *Populus tremuloides* Michx.

**western yew**, *Taxus brevifolia* Nutt.

**white pine weevil**, *Pissodes strobi* (Peck)

**white pine blister rust** (disease), *Cronartium ribicola* J.C. Fisch (agent)

**white mulberry**, *Morus alba* L.

**white-tailed deer**, *Odocoileus virginianus* (Zimm.)